AD A146 099 BASELINE DESIGN REPORT OF EXTENDED PERFORMANCE 1/3
HYDROFOIL PROGRAM PCH-1 FE..(U) GRUMMAN AEROSPACE CORP
BETHPAGE NY 15 NOV 81 MAR-1373-921-1 N00600-76-C-0246
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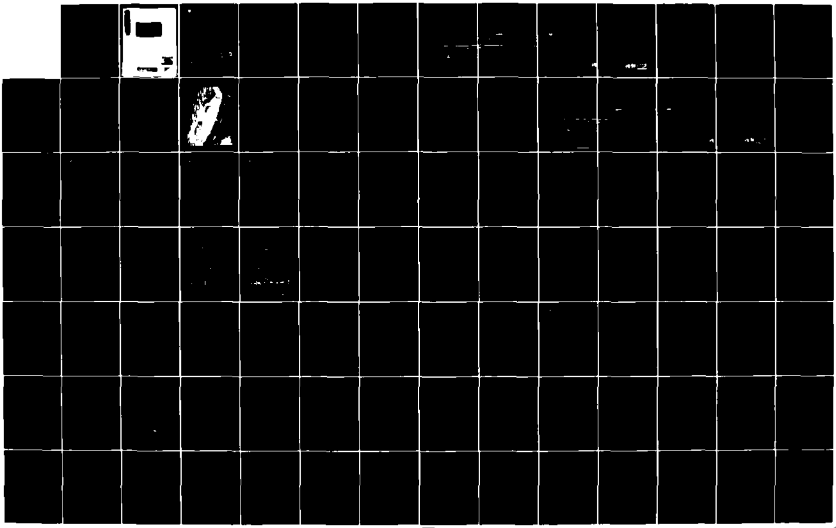

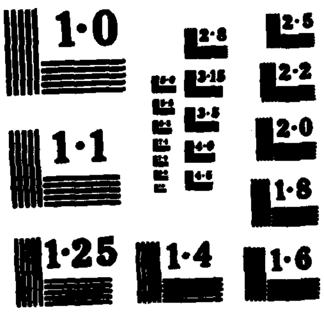
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BASELINE DESIGN REPORT

OF

EXTENDED PERFORMANCE HYDROFOIL PROGRAM

PCH-1 FEASIBILITY DEMONSTRATOR

(1)

BASELINE DESIGN REPORT

OF

EXTENDED PERFORMANCE HYDROFOIL PROGRAM

PCH-1 FEASIBILITY DEMONSTRATOR

Prepared for

Department of the Navy

David W. Taylor Naval Ship Research and Development Center

Betnesda, Maryland

Under

Contract No. N00600-76-C-0246

and N00600-81-D-0877

Report Number MAR 1373-921-1

Prepared By

Grumman Aerospace Corporation

Bethpage, New York 11714

15 December 1980

13 March 1981 - Rev 'A'

15 November 1981 - Rev 'B'

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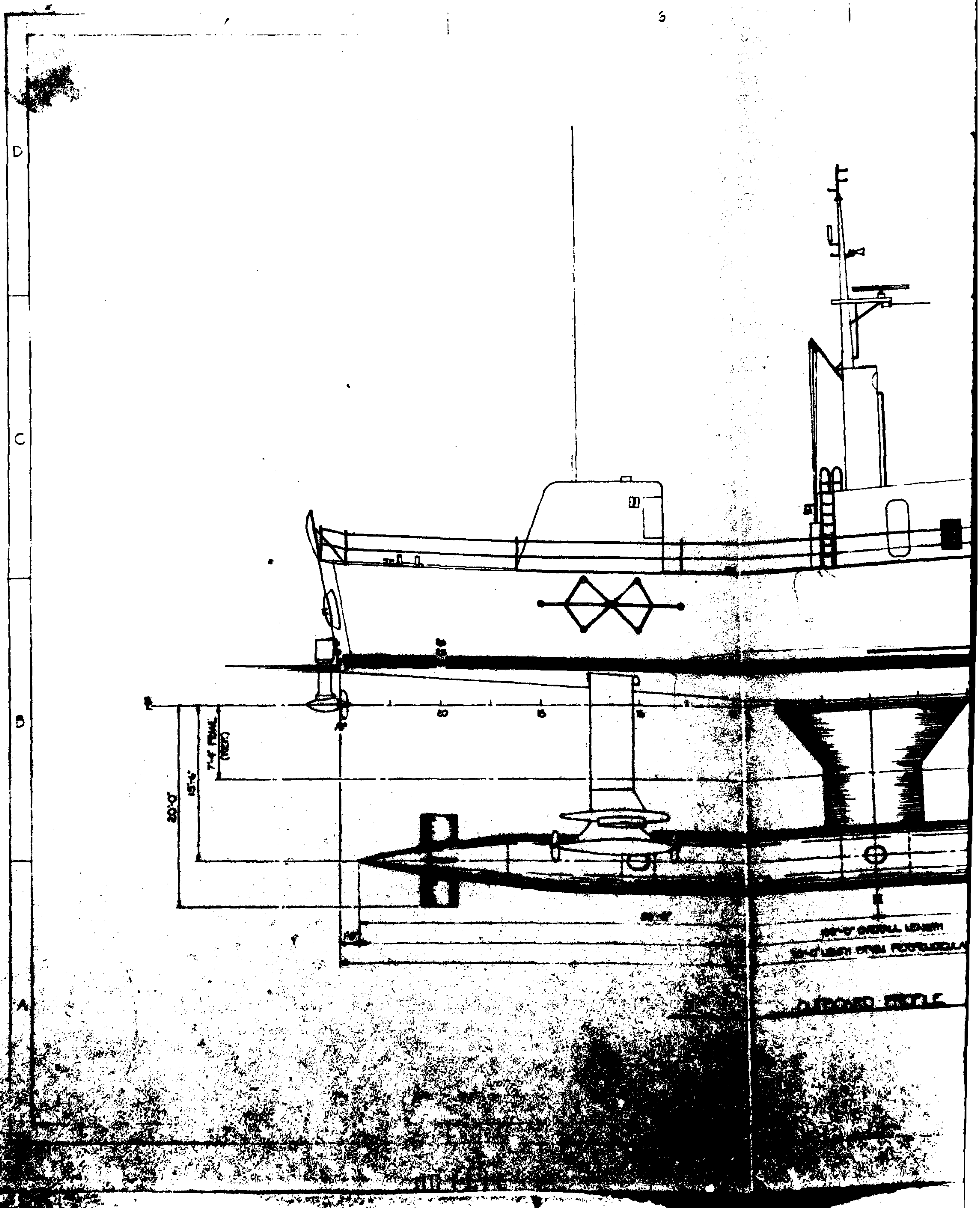
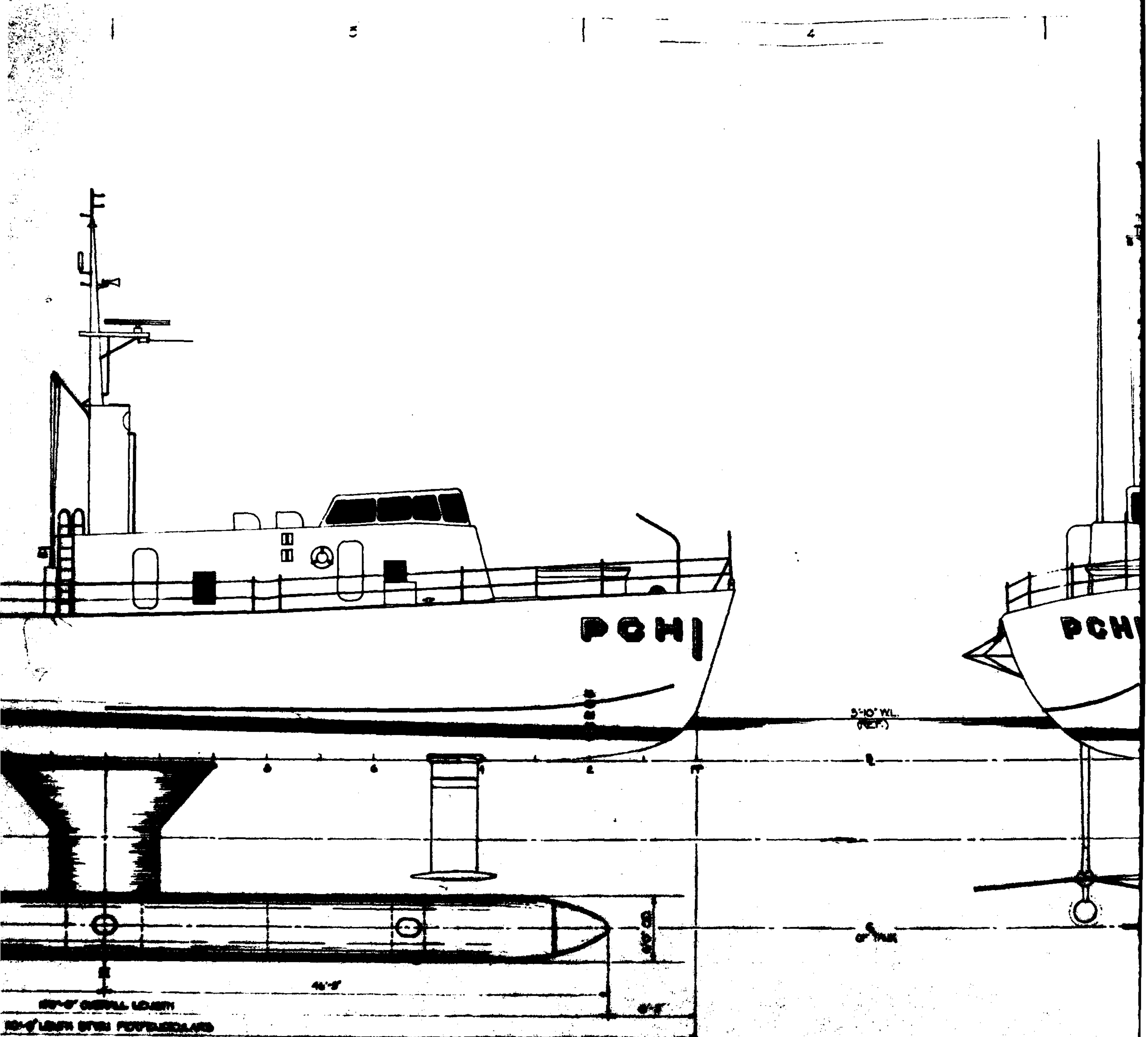

20'-0"
15'-6"
20
15
OVERALL LENGTH



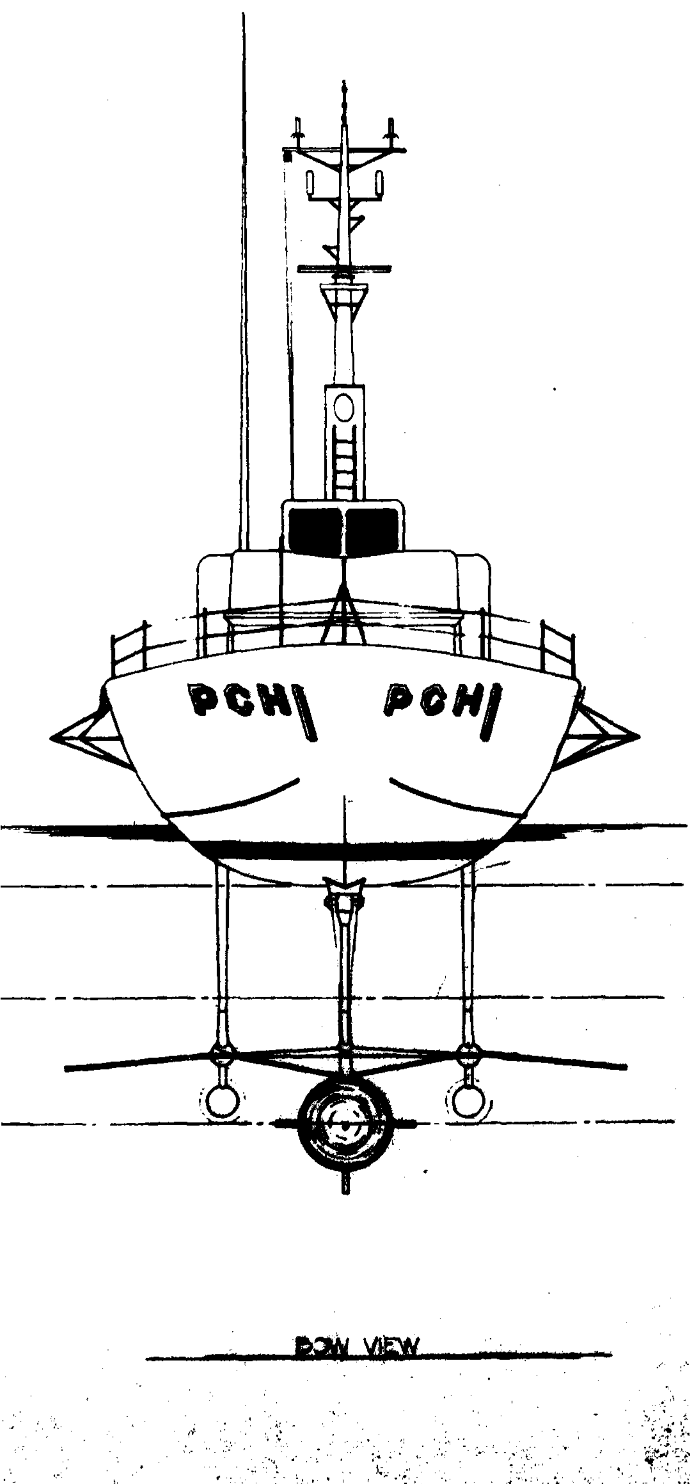
OUTBOARD PROFILE

3

2

PRINCIPAL CRAFT DIMENSIONS

LENGTH OVERALL		115'-9"
LENGTH BETWEEN PERPENDICULARS		110'-0"
BREADTH, MOLDED TO SIDE OF STATION 4		31'-4"
DEPTH, MOLDED TO SIDE OF MAIN DECK AT III		12'-7"
BOTTOM OF KEEL BELOW MOLDED BASELINE		0'-½"



BOW VIEW

2

PRINCIPAL CRAFT DIMENSIONS

LENGTH OVERALL	115'-5"
LENGTH BETWEEN PERPENDICULARS	110'-0"
BREADTH, MOLDED TO SIDE OF STATION 4	31'-4"
DEPTH, MOLDED TO SIDE OF MAIN DECK AT III	12'-7"
BOTTOM OF KEEL BELOW MOLDED BASELINE	0'-½

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APP'D
3	A	REVISED FOREBODY CONTOURS	10 41	[illegible]

D

C

B

A

FIGURE 2-2

LIST OF FIGURES
(Continued)

SYMBOLS

NOTES: 1. Undesignated dimensions are ft./lb./sec./rad.

2. Primed coefficients are normalized by component reference area. Unprimed coefficients are normalized by craft total foil area, 238.48 $ft.^2$

A	ASPECT RATIO OR PROPELLER DISK AREA
a	ACCELERATION
B	BUOYANCY
BHP	TURBINE OUTPUT BRAKE HORSEPOWER
b	SPAN
C	CHORD
C_A	PROFILE DRAG COEFFICIENT ALLOWANCE
C_D	DRAG COEFFICIENT, D/qS
C_F	FRICTION DRAG COEFFICIENT. I.T.T.C. AND HAMA ARE EMPLOYED AS DESIGNATED
C_L	LIFT COEFFICIENT,L/qS
$C_{L\alpha}$	LIFT COEFFICIENT SLOPE, $dC_L/d\alpha$
$C_{L\delta}$	FLAP LIFT COEFFICIENT, $dC_L/d\delta$
C_{L_0}	RESIDUAL LIFT COEFFICIENT, C_L FOR $\alpha = \delta = 0$
C_l	SECTION LIFT COEFFICIENT
$C_{l_{ieff}}$	C_l FOR $\alpha = \delta = 0$ (FOR 16-SERIES SECTION)
$C_{l_{iref}}$	POTENTIAL VALUE OF Cl_{ieff}(FOR 16-SERIES SECTION)
C_l	ROLLING MOMENT COEFFICIENT, ROLLING MOMENT/qSl
C_{l_F}	ROLLING MOMENT COEFFICIENT DUE TO AFT FOIL SIDESLIP
C_M	PITCHING MOMENT COEFFICIENT, PITCHING MOMENT/qSl

SYMBOLS (cont'd)

C_n	YAWING MOMENT COEFFICIENT, YAWING MOMENT/qSl
C_P	PROPELLER POWER COEFFICIENT, P/q AV, INCLUDES WAKE EFFECT
C_T	PROPELLER THRUST COEFFICIENT, T/qA , INCLUDES 5% THRUST DEDUCTION
C_W	TANK WAVE DRAG COEFFICIENT
C_Y	SIDE FORCE COEFFICIENT, Y/qS
C_{Y_β}	SIDE FORCE COEFFICIENT SLOPE, $dCy/d\beta$
C_0, C_1, C_2	DRAG POLAR COEFFICIENTS, $C_D = C_0 + C_1 C_L + C_2 C_L^2$
D	CRAFT DRAG
E	JONES EDGE CORRECTION FACTOR
E_S	SPECIFIC ENDURANCE, RECIPROCAL OF FUEL FLOW
EHP	EFFECTIVE HORSEPOWER, TV/550 = $\eta_G\, \eta$ BHP
G	NORMALIZED CIRCULATION FACTOR
g	ACCELERATION OF GRAVITY, 32.2 FT./SEC.^{2}
h	DEPTH
i	INCIDENCE ANGLE (RELATIVE TO POD)
K_E	HOERNER'S END PLATE FACTOR
L	DYNAMIC LIFT, W-B
l	FOIL BASE LENGTH, DISTANCE BETWEEN FWD. & AFT FOILS = $l_1 + l_2$
l_1	DISTANCE BETWEEN FWD. FOIL AND C.G.
l_2	DISTANCE BETWEEN AFT FOIL AND C.G.
log	TO BASE 10
M	TAKE OFF MARGIN, THRUST/DRAG
m	MASS, W/g
P	PROPELLER POWER, 550 η_G BHP
P_S	STATIC PRESSURE, $\rho gh + 2116$

SYMBOLS (Cont'd)

P_V	VAPOR PRESSURE, 72 psf
PHP	PROPELLER HORSEPOWER, η_G BHP
q	DYNAMIC PRESSURE, $\rho V^2/2$
R	TURN RADIUS
RN	REYNOLDS NUMBER
R_S	SPECIFIC RANGE, $E_s V_K$
S	TOTAL CRAFT FOIL AREA, 238.48 ft.^{2}, OR PRESSURE COEFF., $1 + \sigma$
T	THRUST
THP	THRUST HORSEPOWER, TV/550 = η PHP
V	SPEED, fps
V_K	SPEED, KNOTS
v	SECTION LOCAL VELOCITY DUE TO THICKNESS
Δv	SECTION LOCAL VELOCITY INCREMENT DUE TO CAMBER
$\Delta v_a'$	SECTION LOCAL VELOCITY INCREMENT DUE TO ANGLE OF ATTACK
W	CRAFT WEIGHT
Y	SIDE FORCE
y	LATERAL DISTANCE FROM MID-SPAN ON FOIL, VERTICAL DISTANCE FROM C.G. ON CRAFT
α	CRAFT PITCH ANGLE OR SECTION ANGLE OF ATTACK
α_{0L}	FOIL ANGLE OF ATTACK MEASURED FROM ZERO LIFT ANGLE
$\alpha_{c_l=0}$	SECTION ZERO LIFT ANGLE OF ATTACK
β	SIDESLIP ANGLE
Γ	DIHEDRAL ANGLE
γ	ROLL ANGLE
Δ	INCREMENT
δ	SECTION FLAP ANGLE OR FOIL LIFT FLAP ANGLE
δ'	AILERON ANGLE
δ_R	RUDDER ANGLE

SYMBOLS (Cont'd)

δ_H'	TANK FIN ANGLE
δ_1	DEFLECTION OF A FULL CHORD FLAP OVER SPAN EXTENT OF FLAP
ζ	PROPORTION OF CHORDWISE LIFT DISTRIBUTION DUE TO FLAP WHICH IS OF BASIC TYPE. ζ = .4527 FOR PCH
η	PROPELLER EFFICIENCY OR FOIL SPAN STATION
η_{ac}	FOIL SPAN STATION FOR CENTER OF PRESSURE
η_G	TRANSMISSION EFFICIENCY. 95% EMPLOYED HERE
η_I	IDEAL PROPELLER EFFICIENCY, $2(\sqrt{1+C_T}-1)/C_T$
k	VISCOUS SECTION LIFT CURVE SLOPE/2π = .8993 FOR 16-SERIES SECTION IN PROTOTYPE SCALE
ν	KINEMATIC VISCOSITY = 12.82×10^{-6} FT.^{2}/SEC.
ρ	DENSITY = 1.9905 LB. SEC.^{2}/FT.^{4}
σ	CAVITATION NUMBER, $(P_S-P_V)/q$
ψ	YAW ANGLE
Ω	A FLAP VELOCITY DISTRIBUTION PARAMETER

SUBSCRIPTS

B	DUE TO BUOYANCY
D	A DESIGN OR REFERENCE CONDITION
i, O	INBOARD, OUTBOARD
L	DUE TO LIFT
Min	MINIMUM
Max	MAXIMUM
P	PARASITE
q_D/C	AT THE SPEED FOR q_D/C
S	TANK STRUT
T	TANK
V_D	AT DESIGN OR REFERENCE SPEED
1, 2	FWD., AFT
∞	AT INFINITE DEPTH (AERODYNAMIC)

FOREWORD

Grumman Aerospace Corporation, Advanced Marine System Department, has conducted this investigation into the feasibility of generating a hybrid surface ship by installing a buoyancy/fuel tank on the PCH-1 HIGH POINT under Contract N00600-76-C-0246 and N00600-81-D-0877.

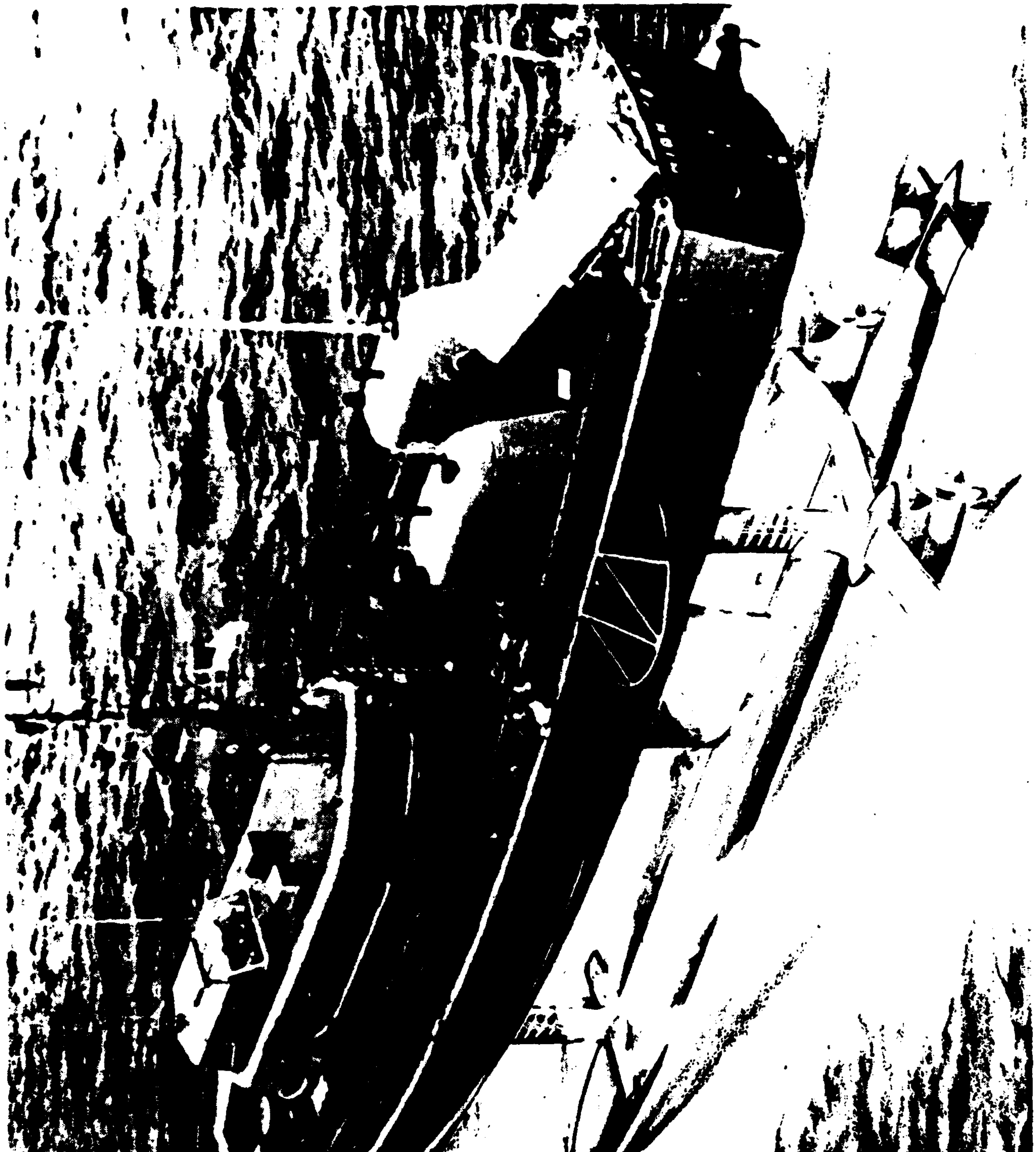
Contact person and Project Manager at the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) was Mr. John Meyer of the Hydrofoil Program Office (Code 1159)(202-227-1709).

This investigation was a continuation of the general exploration into the practicability of enhancing the performance of hydrofoil craft by utilizing an external fuel-carrying buoyancy tank isolated below the craft's fully submerged foils, carried out under the DTNSRDC Ship Feasibility Investigation Block Program (SF43-411-291).

The results of previous efforts are contained in the following Grumman reports:

1) MAR 298-813-1, ASW Hydrofoil Feasibility Study - Range Optimization August 1979.
2) MAR 298-814-2, ASW Hydrofoil Feasibility Study - Technical Study-Final Report, November 1978.
3) MAR 298-818-1, PCH-1 HIGH POINT - Feasibility Investigation of Buoyancy/Fuel Tank Installation - Final Report, January 1980
4) MAR 298-818-1, PCH-1 HIGH POINT - Feasibility Investigation of Buoyancy/Fuel Tank Installation - "Rev. A" September 1980

Schedules for the implementation of the proposal from detail design through sea trials are presented.



SECTION 0

INTRODUCTION

The purpose of the Preliminary Design Investigation was to define the technical validity of using a buoyancy/fuel tank to improve hydrofoil performance and enhance mission capabilities.

The existing hydrofoil craft, PCH-1 HIGH POINT, was selected by DTNSRDC as the R&D platform on which to conduct the developmental investigation. This craft, in the Mod 1 version, with the buoyancy/fuel tank installed is referred to as Hybrid Design M169 in the sections following.

With the exception of the performance discussion, Section 3, Revision 'B' to this report incorporates the developments reflected by the detail design phase of the program. It is recognized that the performance will be degraded by an indeterminate amount due to the increase in craft displacement and dynamic lift requirements which were not further investigated due to Program limitations.

Inasmuch as a weight statement reflecting the current condition of PCH-1 Mod 1 was not available at the onset of this task, it was decided to base all performance calculations on the full load condition weight of 126.20 long tons as recorded on Figure 4-1. It was recognized that the 126.20 tons is an arbitrary figure inasmuch as the full load development included various items of test equipment and test personnel.

It had been anticipated that a minimal effort would be expended to review hullborne performance of the PCH-1 with the buoyancy/fuel tank attached. As an exhaustive search of the data bank, by both Grumman and DTNSRDC revealed that sufficient background information was not available to permit an investigation to be made which would predict hullborne performance with any degree of reliability, none was conducted.

The dynamic lift value of 117.79 L.T. is used throughout the performance calculations of Section 3 inasmuch as it formed the basis for the feasibility and preliminary design investigations of References 15 and 21. As this value falls between the dynamic lifts for the original full load and minimum operating conditions, it is felt that it presents a representative operating condition pending further investigation.

SECTION 1

CONCLUSIONS

1.0 The results of the previously conducted feasiblity and preliminary design investigations for the installation of a buoyancy/fuel tank on the PCH-1 HIGH POINT has indicated that the concept is developable if certain limitations, and uncertainties are accepted.

1.1 A DTNSRDC drag analysis for the buoyancy/fuel tank included wave-making and frictional resistance only. Resistances due to surface roughness, fouling, interference, eddy-making were included in the preliminary design phase of the investigation.

1.2 Buoyancy/fuel tank loads based upon PHM model tests have been investigated in more detail by DTNSRDC (Reference 9) and Grumman (Reference 25) and the results form the basis for the detail design analysis of the Design M169.

1.3 Coordinated turning performance of the craft is limited by aileron cavitation to 2.75 to 3.85 deg./sec. at 30-40 knots, with a rudder angle of 3.1 degrees.

1.4 Although there is an advantage to having a positively buoyant tank in terms of reduced foilborne drag on the foils, there is a limit to the positive buoyancy which can be tolerated without seriously affecting the PCH-1 hullborne intact stability. Thus for safety reasons, the positive buoyancy must not exceeed 11.82 long tons. This will satisfy the given 80 knot gradient wind criteria.

1.5 The methods of attachment investigated have indicated that, for a feasibility installation, the possibility of removing the tank with the craft afloat would be extremely difficult under all conditions regardless of the method adopted, and the concept was therefore eliminated from the detail design.

1.6 To enhance the foilborne and hullborne steering capability, an additional rudder is required on the tank at the centerline aft.

Initially it was assumed that a single rudder above the tank would be satisfactory. However, to insure statical stability, it has been determined that a cruciform arrangement is required, as shown on Figure 2.2.

1.7 Fuel capacity of the B/F tank was predicated on obtaining approximately neutral buoyancy in either full fuel or ballast conditions.

1.8 The possibility for increasing tank buoyancy by blowing ballast water out of selected tanks after fuel has been transferred into the hull tanks has been incorporated into the **detail design.** This has been accomplished by providing a compressed air connection to the fuel transfer lines within the hull.

1.9 One of the major problems is related to the mating of the tank to the hull. Inasmuch as the hull is of aluminum construction and the tank is steel, the isolation of the dissimilar metals is of prime importance.

SECTION 2

CRAFT DESCRIPTION

2.0 The PCH-1 Mod 1 is a canard configured hydrofoil craft with the following principal characteristics, exclusive of the buoyancy/fuel tank:

Length Between Perpendiculars	110.00 Ft.
Length Overall	115.75 Ft.
Beam - (Maximum)	31.28 Ft.
Beam - (DWL)	21.40 Ft.
Draft - (Foils Extended)	19.83 Ft.
Draft - (Foils Retracted)	8.58 Ft.
Displacement - (Light Ship)	99.56 L.T.
Displacement - (Full Load)	126.20 L.T.

With the addition of the buoyancy/fuel tank to the craft, the drafts and displacements are as follows:

Draft	24.25 Ft.
Displacement - (Light Ship)	146.96 L.T.
Displacement - (Full Load - Fuel)	211.36 L.T.

Draft vs. displacement curves are given on Figure 2-1.

2.1 The existing strut/foil installations are arranged for wet retraction. Retraction of the struts with the B/F tank installed is possible as there is no permanent attachment between the B/F tank and the strut/foil system.

Propulsion is provided by two Proteus PT1273 gas turbine engines driving four (4) five bladed sub-cavitating fixed pitch propellers thru bevel gears and strut shafting. The propulsion system is described in greater detail in Section 3.4.

2.2 The new buoyancy/fuel tank is attached to the underside of the hull as shown on Figure 2.2. The attachments are designed so that loads in all axes are resisted at the midship strut, the aft foil connection being capable of taking vertical and side loads only.

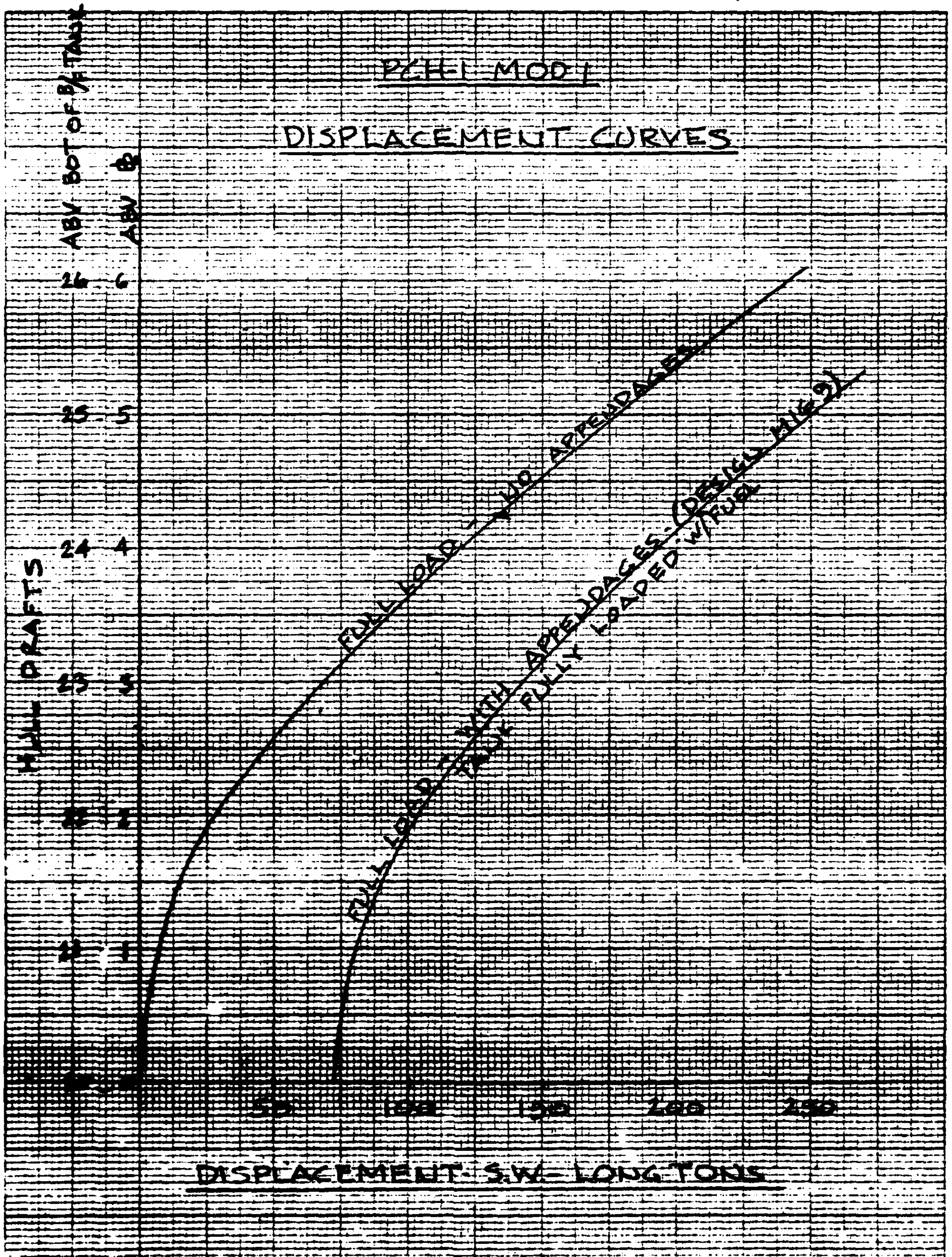
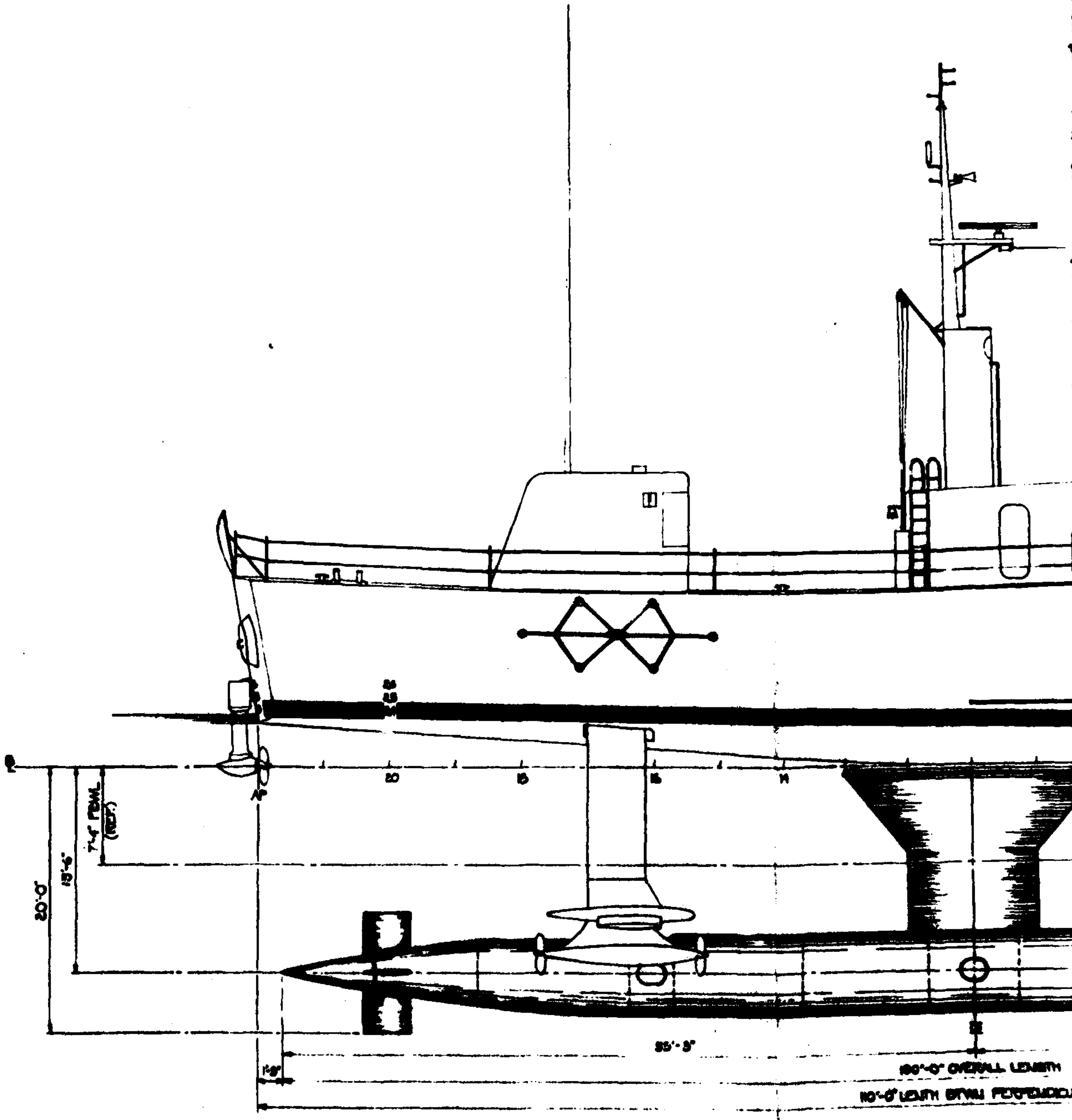
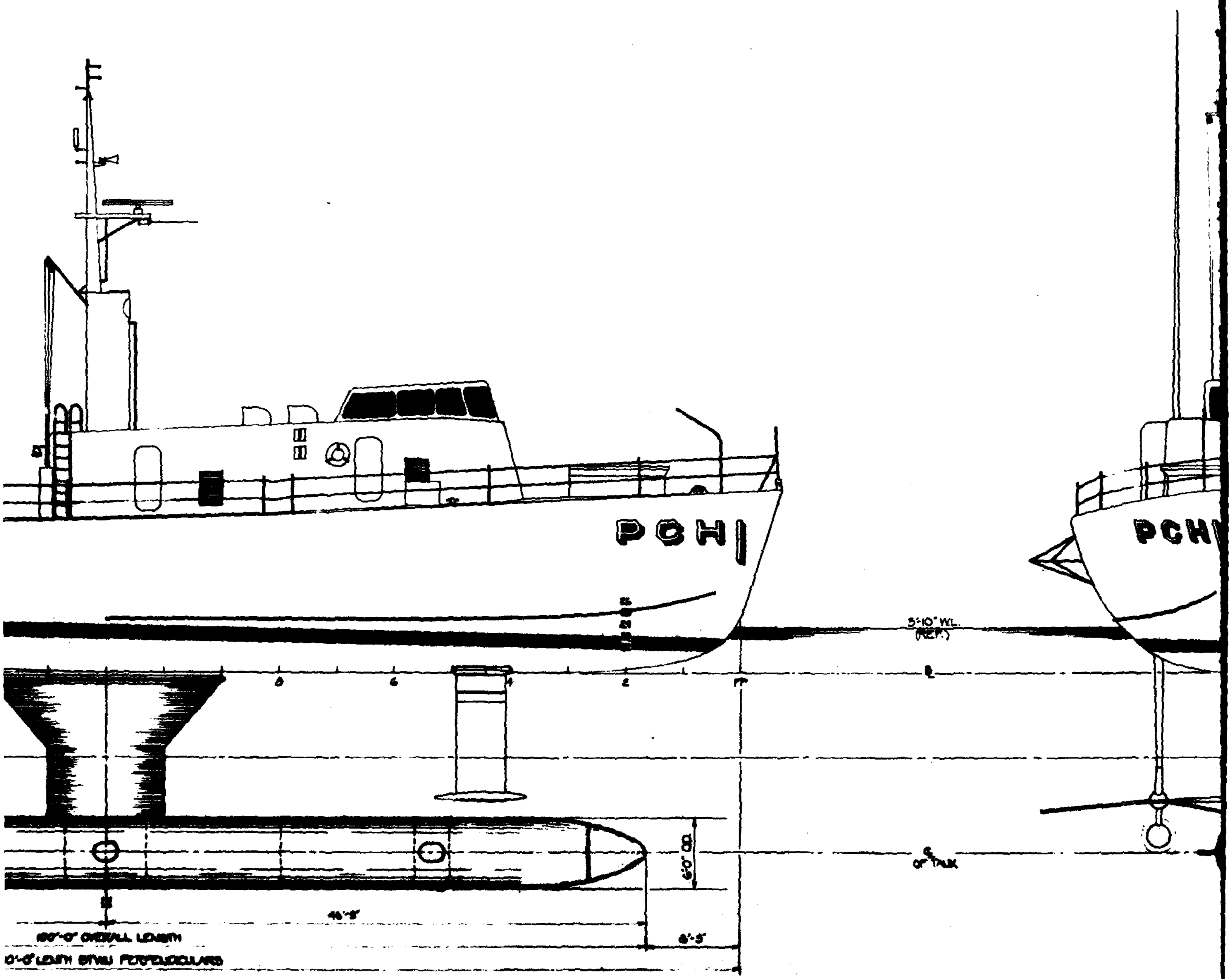

PCH-1 MOD 1
DISPLACEMENT CURVES
HULL DRAFTS
ABV BOT OF B/ TANK
ABV B
26
25
24
23
6
5
4
3
2
1
FULL LOAD - W/O APPENDAGES
FULL LOAD - WITH APPENDAGES - (DESIGN M1E 2)
TANK FULLY LOADED W/FUEL
50
100
150
200
250
DISPLACEMENT S.W. - LONG TONS

FIGURE 2-1



OUTBOARD PROFILE



OUTBOARD PROFILE

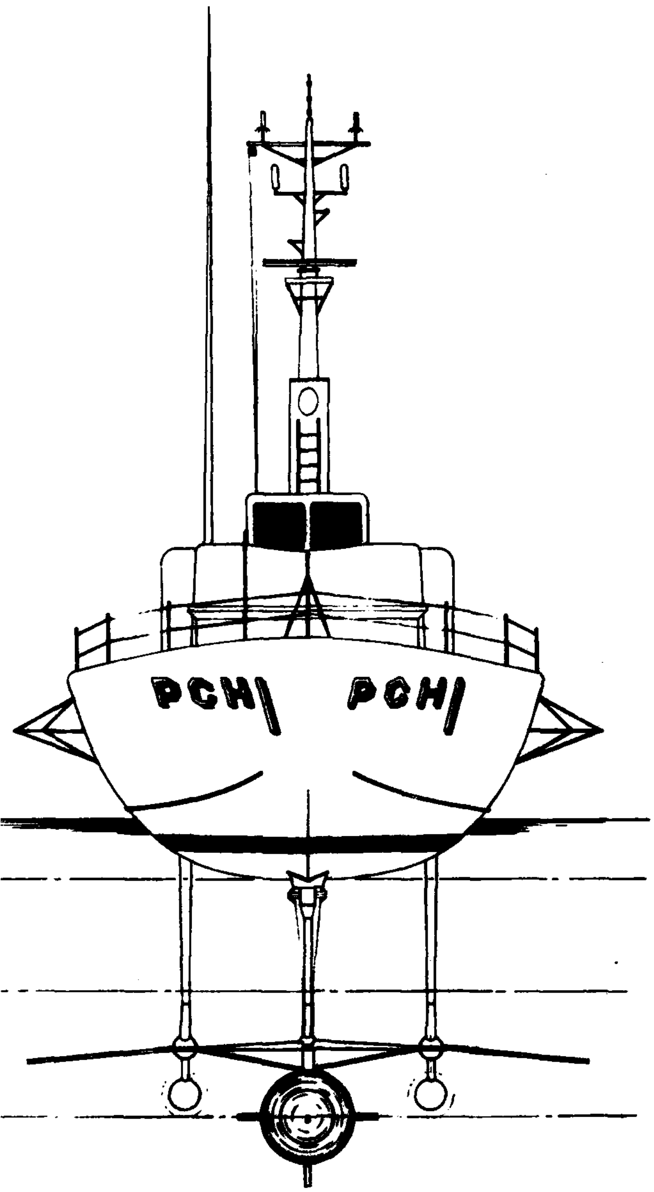
2

3

2

PRINCIPAL CRAFT DIMENSIONS

LENGTH OVERALL		115'-9"
LENGTH BETWEEN PERPENDICULARS		110'-0"
BREADTH, MOLDED TO SIDE OF STATION 4		31'-4"
DEPTH, MOLDED TO SIDE OF MAIN DECK AT III		12'-7"
BOTTOM OF KEEL BELOW MOLDED BASELINE		0'-½



BOW VIEW

A | SH 1

...-CD-6000

3

2

2

PRINCIPAL CRAFT DIMENSIONS

LENGTH OVERALL	115'-5"
LENGTH BETWEEN PERPENDICULARS	110'-0"
BREADTH, MOLDED TO SIDE OF STATION 4	31'-4"
DEPTH, MOLDED TO SIDE OF MAIN DECK AT III	12'-7"
BOTTOM OF KEEL BELOW MOLDED BASELINE	0'-½

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APP'D
[illegible]	A	REVISED FOREBODY CONTOURS	[illegible]	[illegible]

D

C

B

FIGURE 2-2

A

EXTENDED PERF HYDROFOIL MOD
PCH-1 DEMONSTRATOR
CRAFT GEOMETRY

MHP-CD-00105

2

2.2 (Cont'd) To enhance the B/F tank stability and craft steering capability, an additional rudder is added to the B/F tank at the centerline aft.

Fuel and ballast are contained within the same tank compartments, separated by flexible diaphragms. Displacement of either fuel or ballast is accomplished by pressurizing the opposite side of the diaphragm, utilizing ram pressue on the ballast side foilborne, static pressure hullborne, and an existing fuel pump or pressure fueling on the fuel side. Segregation of fuel cells is provided by separate fill/discharge lines to each tank.

SECTION 3

PERFORMANCE

3.0 The following section presents the performance of Design M169. The performance prediction is based largely upon information for the PCH-1 supplied to Grumman by the Hydrofoil Special Trials Unit and the Hydrofoil Program Office at NSRDC.

3.1 Foil System Description and Drag Analysis - The PCH-1 Mod 1 foil system is a canard configuration with twenty-seven and a half percent of the total foil area forward and seventy-two and a half percent aft. The forward "tee" foil has a planform area of 65.63 square feet, a taper ratio of 0.25 and an aspect ratio of 6.10. The aft foil is a "Pi" foil with a planform area of 172.85 square feet, a taper ratio of 1.0 (rectangular), and an aspect ratio of 7.65.

Most of the foil/strut/pod dimensions were obtained from Boeing Drawing No. 25-56103 PRINCIPAL DIMENSIONS PCH-1 Mod 1, dated 5/69. Figures 3-1 thru 3-4 present the dimensions used in the drag analysis of Design M169.

Drag Analysis - The details of the drag analysis performed on Design M169 can be found in Reference 1. The total drag coefficient is presented as a quadratic in the lift coefficient:

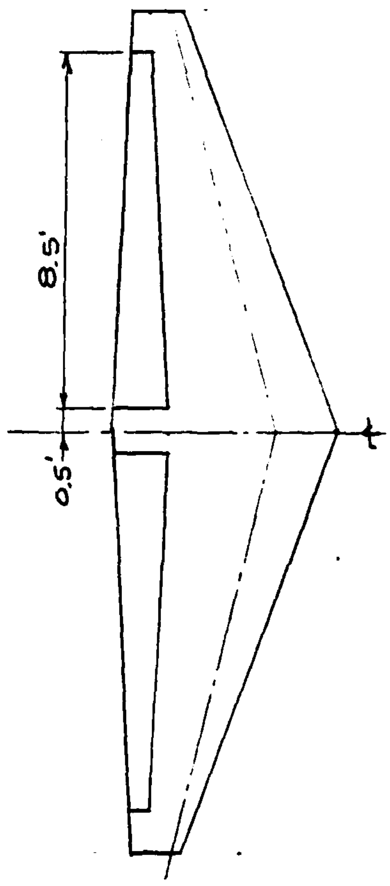
$$C_D = C_0 + C_1 C_L + C_2 C_L^2$$

The PCH-1 Mod 1 drag coefficient is the summation of five individual drag components:

1. Parasite
2. Separation

DESIGN NO.	SUBJECT		WBS
M169	FORWARD FOIL GEOMETRY		
ANALYST	CHECKER	ANALYSIS DATE	PAGE NO.

FORWARD FOIL GEOMETRY	
$S =$	65.63 SQ.FT.
$b =$	20.00 FT.
$C_R =$	5.25 FT.
$C_t =$	1.31 FT.
$\lambda =$	0.25
$AR =$	6.10
MHC =	368 FT
CHORD SECTION - NACA 16-309	
$\Lambda_{c/4} =$	15.00°
$\Lambda_{TE} =$	-1.56°
$\Lambda_{LE} =$	20.00°
$\Lambda_{3c/4} =$	4.07°



$$\Lambda_{x/c} = \tan^{-1}\left[\tan\Lambda_{c/4} + \frac{1-4x/c}{AR}\;\frac{1-\lambda}{1+\lambda}\right]$$

$$\Lambda_{x/c} = \tan^{-1}\left[0.2679 + \frac{1-4x/c}{6.10}\,(0.60)\right]$$

$$\Lambda_{x/c} = \tan^{-1}\left[0.3662 - 0.3934\,x/c\right]$$

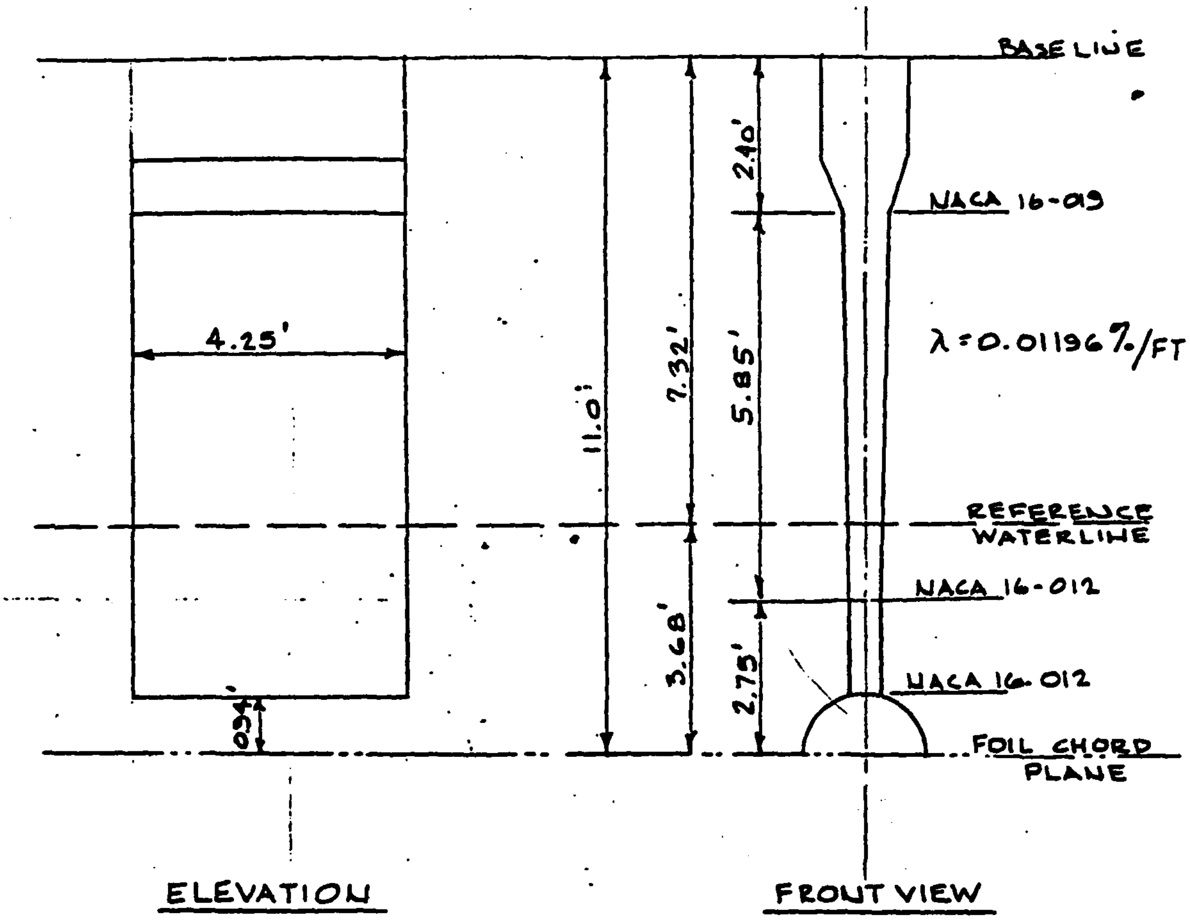
FIGURE 3-1

GRUMMAN ... CORPORATION

MARINE DESIGN ANALYSIS

DESIGN NO.	SUBJECT	WBS
M169	FORWARD STRUT GEOMETRY	

ANALYST	CHECKER	ANALYSIS DATE	PAGE NO.



FORWARD STRUT

FIGURE 3-2

DESIGN NO.	SUBJECT			WBS
M169	AFT FOIL GEOMETRY			
ANALYST	CHECKER	ANALYSIS DATE		PAGE NO.

AFT FOIL GEOMETRY

S = 172.85 SQ. FT.
b = 36.38 FT
$C_r = C_t$ = 4.75 FT.
AR = 7.65
MHC = 4.75 FT.
FOIL SECTION - NACA 16-309

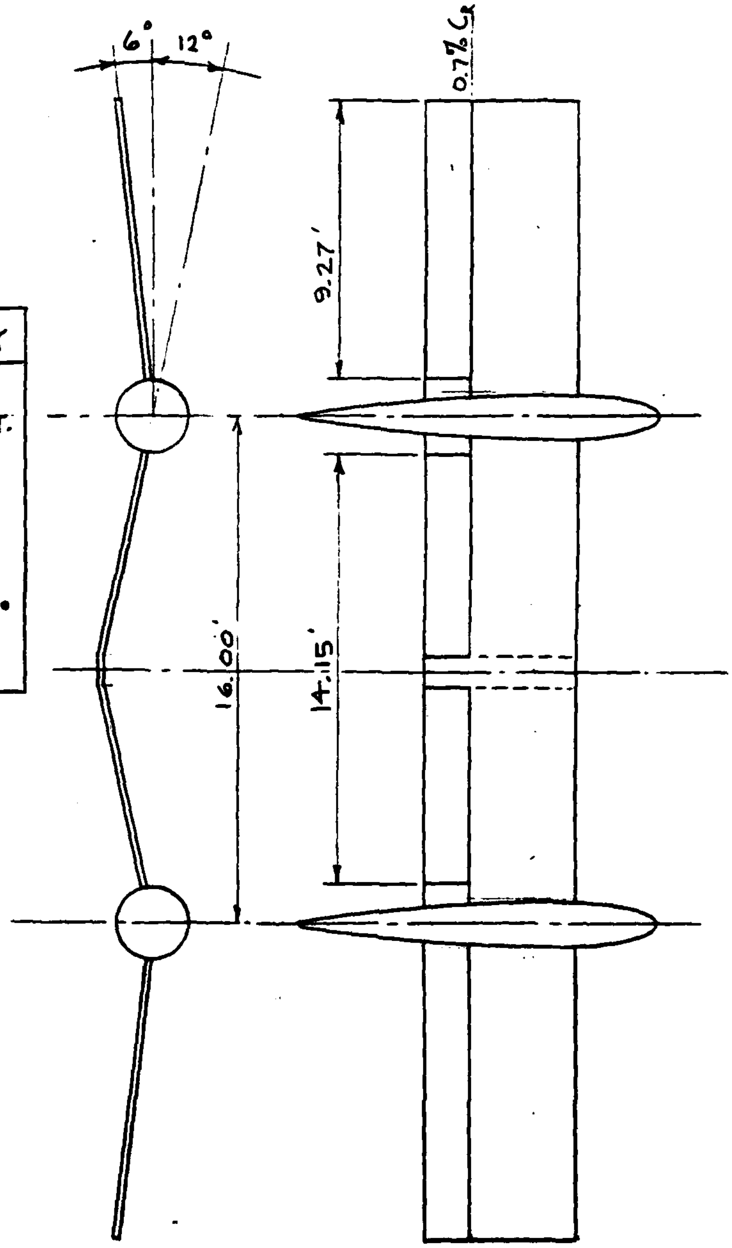


FIGURE 3-3

DESIGN NO.	SUBJECT		WBS
M169	AFT STRUT GEOMETRY		
ANALYST	CHECKER	ANALYSIS DATE	PAGE NO.

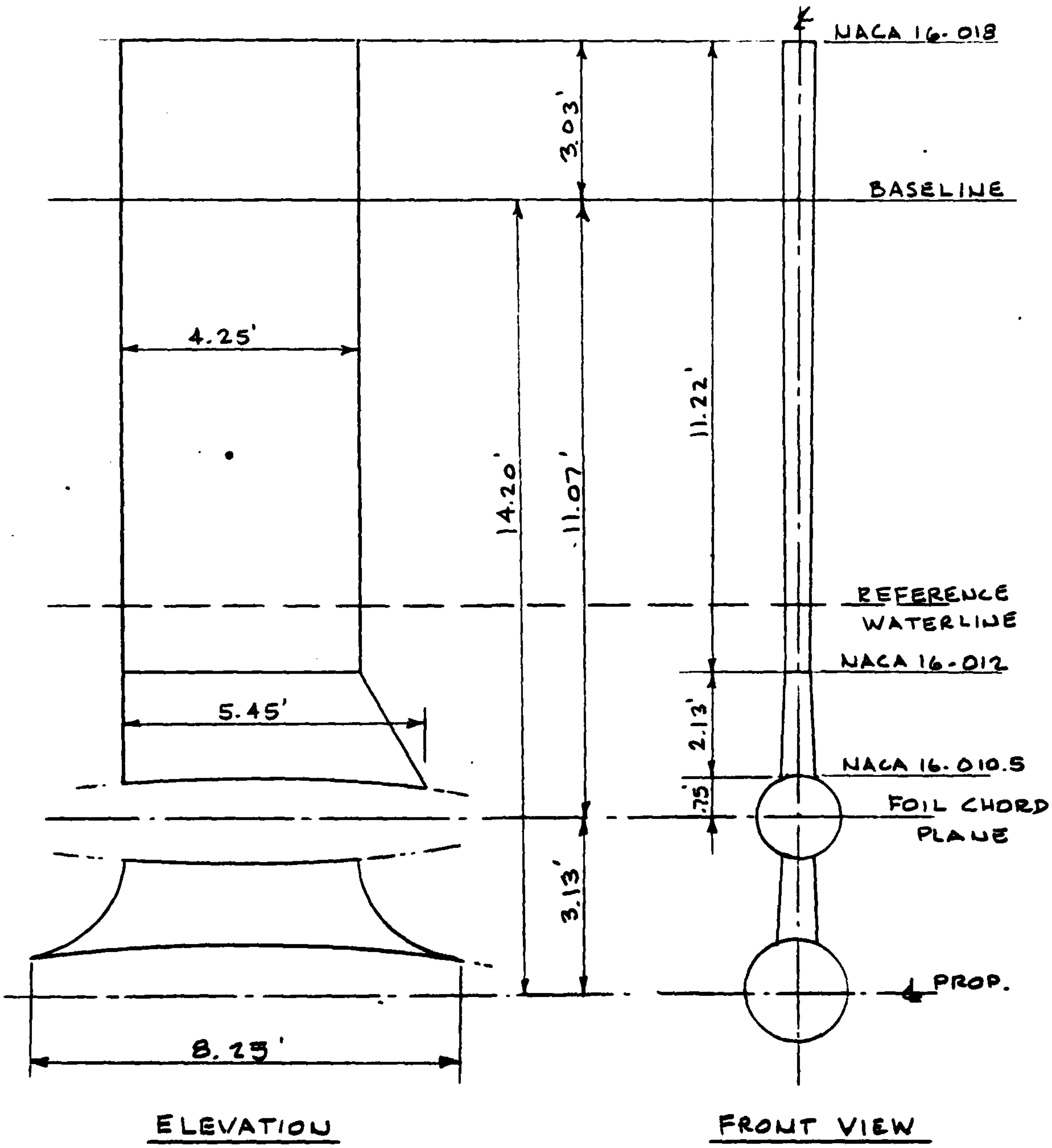


FIGURE 3-4

3.1 (cont'd)

3. Induced
4. Surface Image
5. Wave

Each of these drag components can be expressed as a function of foil geometry except for the parasite drag which has a strong dependency on vehicle size and propulsion system.

The total drag of Design M169 was determined by developing the drag polar for the PCH-1 Mod 1, and then adding the additional drag of the buoyancy/fuel tank and the additional strut and fins.

The parasite drag coefficient is the most complex term of the craft drag polar coefficient equation when that equation is expressed in general form. It is the sum of many components of distinct reference areas, where those distinct reference areas do not necessarily have a fixed relationship to the variable total foil area, which is the reference for the total parasite drag coefficient. The parasite drag coefficient must contain the effect of foil planform, submergence and speed, and must do so in an analytical form which promotes the definition of optimization.

The derivation of the parasite drag coefficient is presented in detail in Reference 2. The parasite drag coefficient for PCH-1 is summarized in Figures 3-5 thru 3-7. Figure 3-5 is a compilation of the profile drag for each component in the foil system. Figure 3-6 is the generalized parasite drag coefficient components normalized to the total foil area, and Figure 3-7 is the generalized parasite drag coefficient components for a total foil area of 238.48 square feet. The total parasite drag coefficient for the PCH-1 Mod 1 becomes a function of foil submergence only:

$$C_{D_p} = 5.0965 \times 10^{-6} h^2 + 4.4492 \times 10^{-4} h + 1.0978 \times 10^{-2}$$

PROFILE DRAG SUMMARY

COMPONENT	FRICTION DRAG COEFFICIENT		PROFILE DRAG COEFFICIENT	
	Forward	Aft	Forward	Aft
FOILS	$2.59906 \times 10^{-3} + C_r$ (3.1189 X 10^{-3})*	$2.5003 \times 10^{-3} + C_r$ (3.0004 X 10^{-3})	$2.216\ C_{f_1}$	$2.216\ C_{f_2}$
STRUTS	$2.5426 \times 10^{-3} + C_r$ (3.0511 X 10^{-3})	$2.5426 \times 10^{-3} + C_r$ (3.0511 X 10^{-3})	$2.2485 + 0.0144H\ C_{f_1}$	$2.253 + 0.00636h\ C_{f_2}$
PODS	$2.3154 \times 10^{-3} + C_r$ (2.7785 X 10^{-3})	$2.2053 \times 10^{-3} + C_r$ (2.6464 X 10^{-3})	$1.0791\ C_{f_1}$	$1.0730\ C_{f_2}$
NACELLES	—	$2.27035 \times 10^{-3} + C_r$ (2.7244 X 10^{-3})	—	$1.13703\ C_{f_n}$
PROPULSION STRUT	—	$2.40875 \times 10^{-3} + C_r$ (2.8905 X 10^{-3})	—	$2.336\ C_{f_n}$

* ASSUMES C_r = 20%

FIGURE 3-5

GENERALIZED DRAG COEFFICIENTS

COMPONENT	GENERALIZED DRAG COEFFICIENTS	
	FORWARD ARRAY	AFT ARRAY
FOILS	$\frac{0.41799}{S}$	
PODS	$\frac{26.060}{S} C_{f_1}$	
STRUTS	$\frac{4.25h-3.995}{S}\left[2.2485 + 0.0144h\right] C_{f_1}$	$\frac{8.5h-2.516}{S}$ 2.253 + 0.00636h C_{f_2}
SPRAY	$\frac{6.2008X10^{-4}h^2+9.031X10^{-3}h+3.2894X10^{-2}}{S}$	$\frac{1.2177X10^{-4}h^2+4.8569X10^{-3}h+4.8433X10^{-2}}{S}$
AIR	$\frac{0.3166}{S}$	—
NACELLE	—	$\frac{101.764 C_{f_n}}{S}$
PROPULSION STRUT	—	$\frac{0.18485}{S}$

FIGURE 3-6

PCH-1 MOD 1 DRAG COEFFICIENTS ($S = 238.48\ FT^2$)

COMPONENT	GENERALIZED DRAG COEFF.	
	FORWARD ARRAY	AFT ARRAY
FOILS	1.7527×10^{-3}	4.3423×10^{-3}
PODS	3.0362×10^{-4}	9.5780×10^{-4}
STRUT SPRAY	$2.6 \times 10^{-6} h^2 + 3.7869 \times 10^{-5} h + 1.3793 \times 10^{-4}$	$(5.11 \times 10^{-7} h^2 + 2.0366 \times -0^{-5} h + 2.0310 \times 10^{-4}) \times 2$
STRUT	$7.82986 \times 10^{-7} h^2 + 1.21584 \times 10^{-4} h - 1.14923 \times 10^{-4}$	$6.91637 \times 10^{-7} h^2 + 2.448 \times 10^{-4} h - 7.25232 \times 10^{-5}$
AIR	1.3276×10^{-3}	
NACELLE	–	1.16255×10^{-3}
PROPULSION STRUT	–	7.7516×10^{-4}
TOTAL*	$3.3829 \times 10^{-6} h^2 + 1.5939 \times 10^{-4} h + 3.4069 \times 10^{-3}$	$1.7136 \times 10^{-6} h^2 + 2.8553 \times 10^{-4} h + 7.5715 \times 10^{-3}$

* AIR DRAG IN FORWARD ARRAY TOTAL

FIGURE 3-7

3.1 (cont'd) The incremental foil profile drag (separation drag) is significant in hydrofoil design due to cavitation considerations and foil section selection. The separation drag coefficient is inherently of polar drag form:

$$C_{D_{sep}} = \lambda \text{ sep} \left\{ C_L - C\ell_i \right\}^2$$

Where λ sep and $C\ell_i$ are foil section characteristics, and for Design M169 take the values:

$$C_{D_{sep}} = 0.005 \left\{ C_L - 0.3 \right\}^2$$

The classical aerodynamic value of the induced drag coefficient is employed and appears in the drag polar as:

$$C_{D_i} = \frac{1 + \delta}{\pi AR} C_L^{\,2}$$

Where δ is a circulation distribution factor which is a function of aspect ratio and taper ratio. For the forward foil, the circulation distribution factor is 0.0153 and for the aft foil 0.0666

The exact form of the surface image drag is still a matter of academic debate, but past experience indicates that Wadlins' formulation is a good approximation. The surface image drag coefficient is written as:

$$C_{D_{surf}} = \frac{K_1 c}{8\pi} \quad \frac{1}{\cos\Lambda} \quad C_L^{\,2}$$

Where:

$$\frac{K_1 c}{8\pi} = \frac{AR}{2\pi\left\{16\left(\frac{h^2}{c}\right) + AR^2\right\}} \left[\frac{1}{\sqrt{16\left(\frac{h^2}{c}\right) + AR^2 + 1}} + 1 \right]$$

3.1 (cont'd) The three dimensional foil wave drag is assumed to be proportional to the two dimensional form with the constant of proportionality being a function of submergence only.

$$C_{D_W} = \frac{K_b - 1}{h/c} \; \frac{e^{-2/F_{h_d}^{2}}}{2F_{h_d}^{2}} \; C_L^{2}$$

Where: F_h depth Froude Number $= \frac{V}{gh}$

h/c = foil submergence/mean hydrodynamic chord.

For conservatism we assume the constant of proportionality (K_b-1) equals 1.0.

In order to include the effect of the longitudinal center of gravity on drag, the following expressions are employed:

$$C_{L_1} = \left\{1 - \frac{\ell_1}{\ell}\right\} \frac{S}{S_1} \; C_L$$

$$C_{L_2} = \frac{\ell_1}{\ell} \; \frac{S}{S_2} \; C_L$$

Where:

ℓ_1 = distance from forward foil C_p to LCG

ℓ = distance between forward and aft foil C_p's.

S_1 = foil area forward

S_2 = foil area aft

S = total foil area

For the PCH-1 Mod 1:

$$C_{L_1} = 1.1497 C_L$$

$$C_{L_2} = 0.9431 C_L$$

3.1 (cont'd) and the total drag polar equation takes the form:

$$C_{D_T} = C_{0_T} + C_{1_T} C_L + \left\{ 0.36376C_{2_1} + 0.64466C_{2_2} \right\} C_L^2$$

where:

$$C_{0_T} = 5.0965 \times 10^{-6} h^2 + 4.4492 \times 10^{-4} h + 1.1428 \times 10^{-2}$$

$$C_{1_T} = -0.003$$

$$C_{2_1} = 0.05798 + \frac{1.005}{1.1815h^2+37.21} \left[\frac{1}{\sqrt{1.1815h^2+38.21}} + 1 \right] + \frac{20.772}{V_k^2} e^{\frac{-22.5784h}{V_k^2}}$$

$$C_{2_2} = 0.04938 + \frac{1.2175}{0.7091h^2+58.522} \left[\frac{1}{\sqrt{0.7091h^2+59.522}} + 1 \right] + \frac{26.812}{V_k^2} e^{\frac{-22.5784h}{V_k^2}}$$

The total drag polar coefficients for the PCH-1 Mod 1 are summarized in Figure 3-8.

A decomposition of the parasite drag for the PCH-1 at a four foot submergence is presented in Figure 3-9. The parasite drag of the buoyancy/fuel tank is not included in this figure.

The drag for Design M169 is obtained by adding the drag of the buoyancy/fuel tank, fins and the added strut to the drag of the PCH-1 Mod 1 and is as shown on Figure 3-18.

PCH-1 MOD 1 TOTAL DRAG POLAR COEFFICIENT

DRAG COMPONENT	C_o	C_1	C_2
PARASITE	$5.0965 \times 10^{-6} h^2 + 4.492 \times 10^{-4} h + 1.0978 \times 10^{-2}$	—	—
INDUCED	—	—	0.05298 (0.04438)*
SEPARATION	4.5×10^{-4} (4.5×10^{-4})	-0.003 (-0.003)	0.005 (0.005)
SURFACE	—	—	$\frac{1.005}{1.1815h^2+37.21} \left\{ \sqrt{\frac{1}{1.1815h^2+38.21}} + 1 \right\}$ $\left(\frac{1.2175}{0.7091h^2+58.522} \left\{ \sqrt{\frac{1}{0.7091h^2+59.522}} + 1 \right\} \right)$
WAVE	—	—	$\frac{20.772}{V_K^2} e^{\left[\frac{-22.5784h}{V_K^2}\right]}$ $\left(\frac{26.812}{V_K^2} e^{\left[\frac{-22.5784h}{V_K^2}\right]} \right)$

* NUMBERS IN ( ) ARE AFT ARRAY

FIGURE 3-8

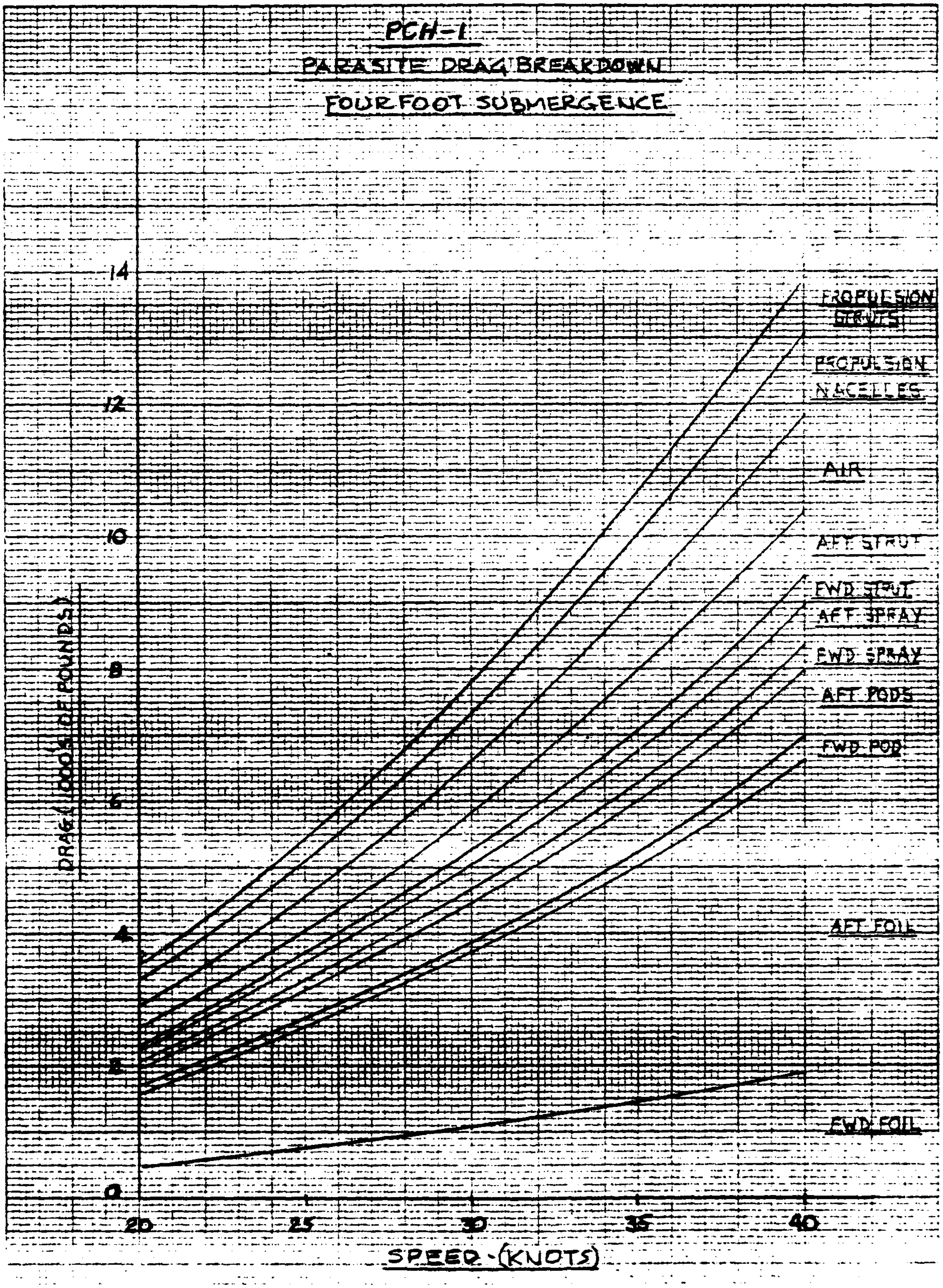

PCH-1
PARASITE DRAG BREAKDOWN
FOUR FOOT SUBMERGENCE
DRAG (000's OF POUNDS)
SPEED - (KNOTS)
PROPULSION STRUTS
PROPULSION NACELLES
AIR
AFT STRUT
FWD STRUT
AFT SPRAY
FWD SPRAY
AFT PODS
FWD POD
AFT FOIL
FWD FOIL
0
2
4
6
8
10
12
14
20
25
30
35
40

FIGURE 3-9

3.1.1 PCH Cruise Drag Polar - For a four foot depth the PCH drag polar of Section 3.1 of Reference 1 can be written:

$$C_D = .013290 - .003C_L + \left(.072869 + \frac{24.841}{V_K^2} e^{-90.312/V_K^2}\right) C_L^2 \qquad (3.1\text{-}1)$$

which is the equation for the PCH drag curves of Figures 3-11 and 3-12 of Reference 15.

The exponential term of Equation 3.1-1 can be written in the general form:

$$\Delta C_D = \frac{24.841}{V_K^2} e^{-90.312/V_K^2} C_L^2$$

$$= \frac{24.841 \times 2.8387}{q} e^{-90.312 \times 2.8387/q} \left(\frac{C_L}{C_{L_{V_D}}}\right)^2 C_{L_{V_D}}^2$$

$$= \left(\frac{q_D}{q}\right)^3 \times \frac{70.516}{q_D} \left(e^{-\frac{256.37}{q_D}}\right)^{q_D/q} C_{L_{V_D}}^2 \qquad (3.1\text{-}2)$$

For a 40 knot design speed:

$$\Delta C_D = .015525 (.94512)^{q_D/q} \left(\frac{q_D}{q}\right)^3 C_{L_{40}}^2 \qquad (3.1\text{-}3)$$

For the design speed and 3/4 and 1/2 design speed $q\left(\frac{q_D}{q} = 1, \frac{4}{3}, \text{and } 2\right)$, this increment becomes:

$$\Delta C_D = .014673\, C_{L_{40}}^2$$
$$\Delta C_{D_{3q_D/4}} = .034132\, C_{L_{40}}^2$$
$$\Delta C_{D_{q_D/2}} = .11094\, C_{L_{40}}^2 \qquad (3.1\text{-}4)$$

3.1.1 which may be written in drag polar form as:
(Cont'd)

$$\Delta C_D = C_{0_{\Delta C_D}} + C_{1_{\Delta C_D}} C_L + C_{2_{\Delta C_D}} C_L^2$$

where:

$$C_{0_{\Delta C_D}} = 8\Delta C_{D_0} - 9\Delta C_{D_{3\theta_0/4}} + 2\Delta C_{D_{\theta_0/2}} = .032076\, C_{L_{40}}^2$$

$$C_{1_{\Delta C_D}} = \left(-10\Delta C_{D_0} + \frac{27}{2}\Delta C_{D_{3\theta_0/4}} - \frac{7}{2}\Delta C_{D_{\theta_0/2}}\right)\Big/ C_{L_{40}} = -.074238\, C_{L_{40}}$$

$$C_{2_{\Delta C_D}} = \left(3\Delta C_{D_0} - \frac{9}{2}\Delta C_{D_{3\theta_0/4}} + \frac{3}{2}\Delta C_{D_{\theta_0/2}}\right)\Big/ C_{L_{40}}^2 = .056835$$

(3.1-5)

Substituting this result into Equation 3.1-1 the drag polar may be written:

$$C_D = .01325 + .032076\, C_{L_{40}}^2 - \left(.003 + .074238\, C_{L_{40}}\right) C_L + .12970\, C_L^2$$

$$= C_{D_P} + C_{D_L}$$

where $C_{D_P} = .01284$ (3.1-6)

The significant characteristics of Equation 3.1-6 are shown in Figure 3.10 for dynamic lifts of 90, 117.79, and 120 long tons. The drag polars are shown on Figure 3-11 and the dimensional equivalents are compared with the exponential form, Equation 3.1-1, on Figure 3-12. The drag polar has been fit to that speed range significant to the craft cruise performance.

PCH CRUISE DRAG POLARS 4 FT. DEPTH

CHARAC.	L = 120LT				L = 117.79LT				L = 90LT			
	C_L	C_D	VALUE	V_K	C_L	C_D	VALUE	V_K	C_L	C_D	VALUE	V_K
$C_{D_{MIN}}$	.082587	.014380	.014380	69.338	.081280	.014336	.014336	69.246	.064830	.013856	.013856	67.775
V_D	.24816	.017936	-	40	.24359	.017753	-	40	.18612	.015764	-	40
$(\sqrt{C_L}/C_D^{1/3})_{max}$	.28277	.019578	7.3204	37.472	.28186	.019554	7.3146	37.185	.27140	.019390	7.2180	33.125
$(L/D)_{max}$	.34307	.023181	14.800	34.020	.34226	.023170	14.772	33.745	.33322	.023199	14.363	29.894
$(C_L^{3/2}/C_D)_{max}$	.51733	.038894	9.5668	27.704	.51707	.038968	9.5415	27.455	.51595	.040251	9.2073	24.024

L = 120LT: $C_D = .015265 - .021423C_L + .1297C_L^2$; $D/1{,}000 = .010334V_K^2 - 5.7585 + 13843/V_K^2$

L = 117.79LT: $C_D = .015193 - .021084C_L + .1297C_L^2$; $D/1{,}000 = .010285V_K^2 - 5.5630 + 13338/V_K^2$

L = 90LT: $C_D = .014401 - .016817C_L + .1297C_L^2$; $D/1{,}000 = .009749V_K^2 - 3.3903 + 7786.6/V_K^2$

Max. $\sqrt{C_L}/C_D^{1/3}$ presents max R_s for constant P.C. and SFC proportional to $P^{-1/3}$

Max. L/D presents min. Drag

Max. $C_L^{3/2}/C_D$ presents min THP

FIGURE 3-10

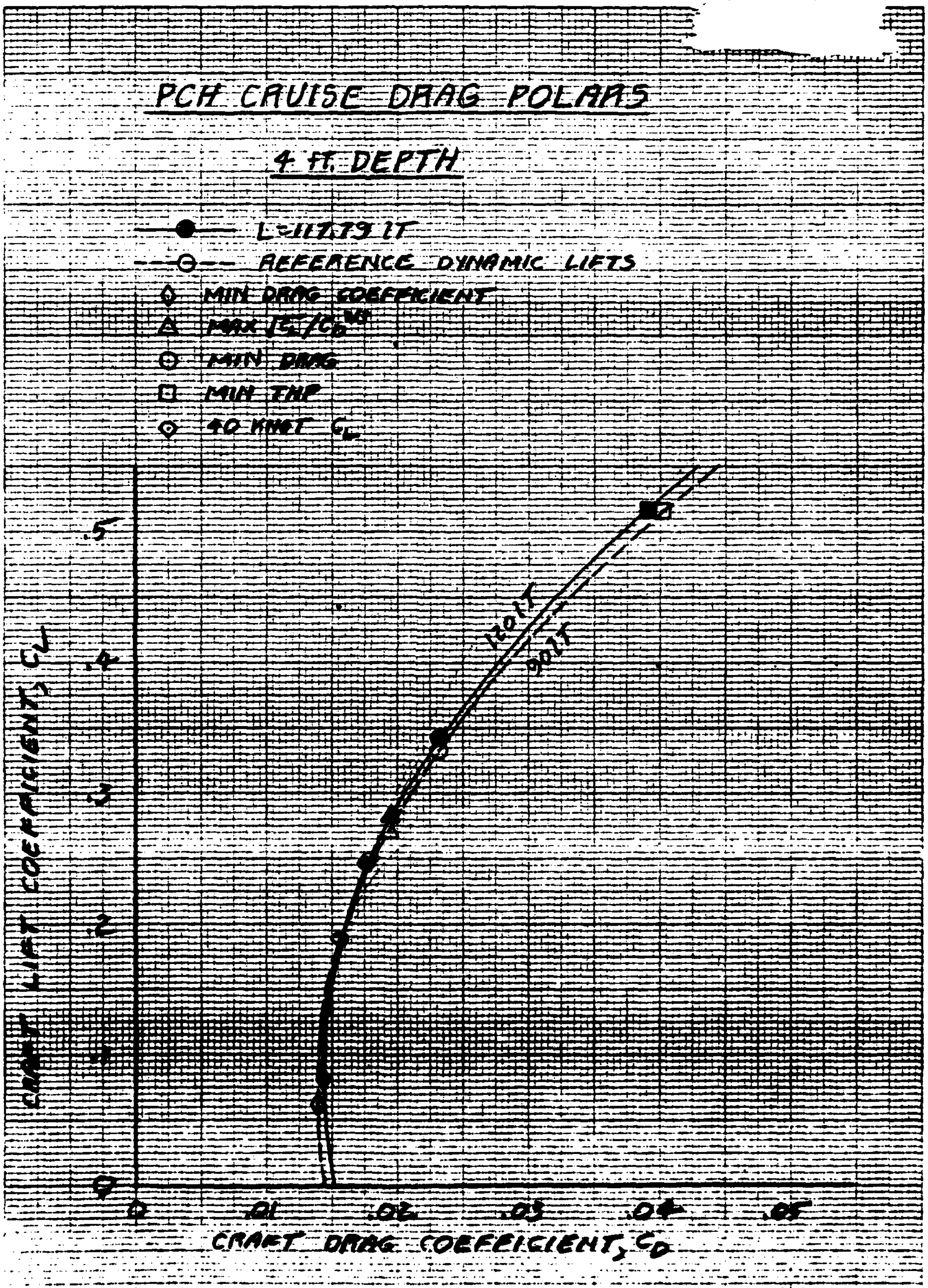

PCH CRUISE DRAG POLARS
4 FT. DEPTH
L=117.79 FT
REFERENCE DYNAMIC LIFTS
MIN DRAG COEFFICIENT
MAX C_L/C_D
MIN DRAG
MIN THP
40 KNOT C_L
120 FT
90 FT
CRAFT LIFT COEFFICIENT, C_L
CRAFT DRAG COEFFICIENT, C_D
0
.1
.2
.3
.4
.5
.01
.02
.03
.04
.05

FIGURE 3-11

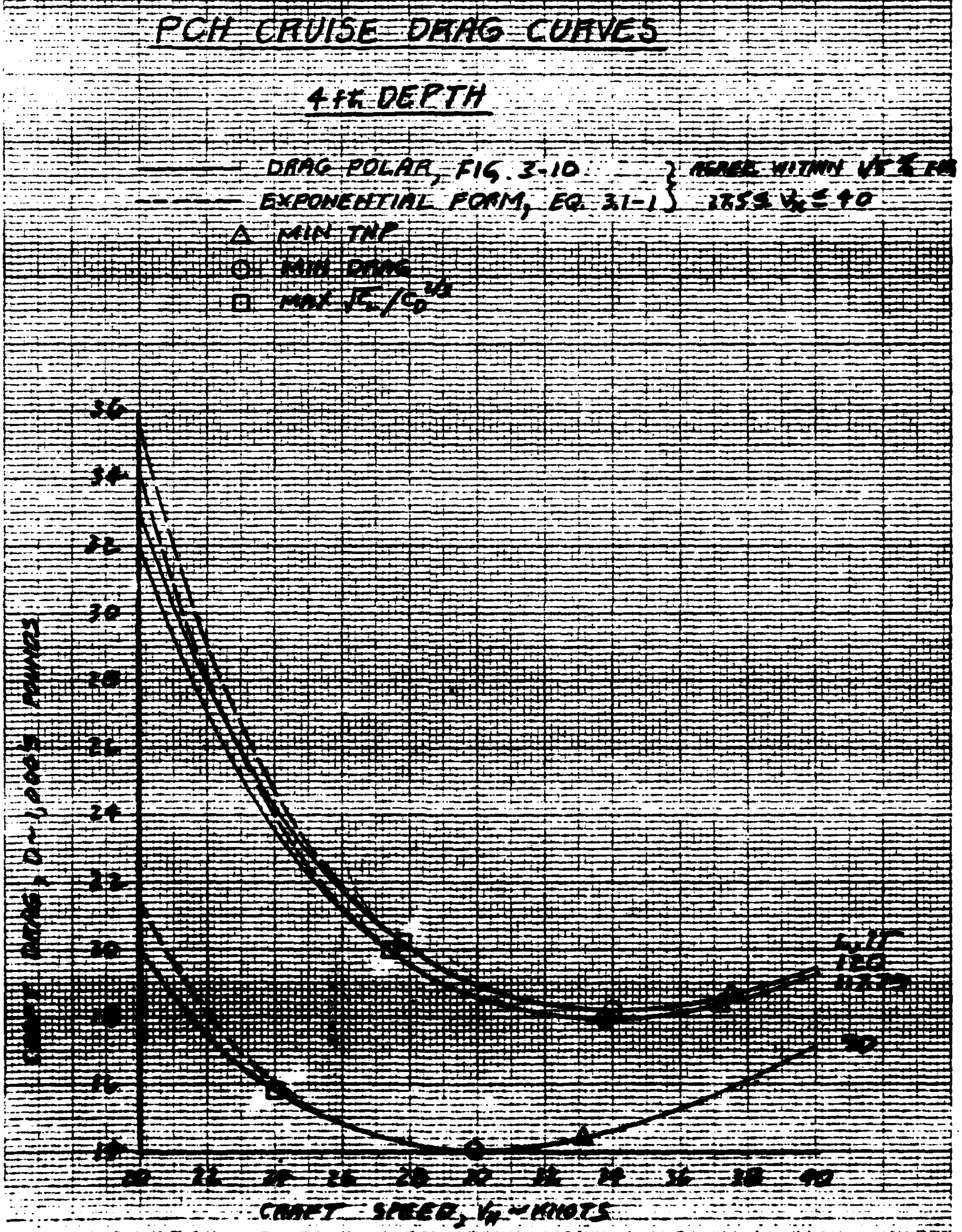

PCH CRUISE DRAG CURVES
4 ft DEPTH
DRAG POLAR, FIG. 3-10
EXPONENTIAL FORM, EQ. 3.1-1
MIN THP
MIN DRAG
CRAFT DRAG, D ~ 1,000's POUNDS
CRAFT SPEED, V ~ KNOTS
120
90
20
22
24
26
28
30
32
34
36
38
40

FIGURE 3-12

3.2 (Cont'd) Referenced to the craft foil area the tank strut spray drag employed is:

$$C_{D_{spray/strut}} = .24\left(\frac{t}{c}\right)^2 \frac{c^2}{S}$$

$$= .24(.12)^2 \frac{(10)^2}{238.48}$$

$$= .0014492$$

(3.2-6)

The total tank strut drag coefficient is the sum of Equations 3.2-5 and 3.2-6:

$$C_{D_{strut}} = .0028186 + \frac{.00005}{C_{L_{40}}} C_L$$

(3.2-7)

Vertical and lateral tank fins of 9 ft. span and 3.5 ft. chord each are employed. Over the 20-40 knot speed range the Schoenherr coefficient for each of these fins is:

$$RN \times 10^{-6} = \frac{1.6889 \times 3.5\, V_K}{12.82} = 9.2218 \text{ to } 18.443$$

$$C_f = .0029224 \text{ to } .0026192$$

$$= .0025181 + \frac{.0001011}{C_{L_{40}}} C_L \qquad (3.2\text{-}8)$$

Only 7.45 ft. of the span of each fin is exposed. For the two fins with a 20% drag allowance and referenced to the craft foil area, the fin drag coefficient becomes:

$$C_{D_{fin}} = 1.2 \times 2 (1 + 1.2 \times .12) C_f \times \frac{2 \times 7.45 \times 3.5}{238.48}$$

$$= .60040\, C_f$$

$$= .0015119 + \frac{.0000607}{C_{L_{40}}} C_L \qquad (3.2\text{-}9)$$

3.2 For the 100 ft. tank the 20-40 knot Reynolds Number variation is:
(Cont'd)

$$RN \times 10^{-6} = \frac{1.6889 \times 100 V_K}{12.82} = 263.48 \text{ to } 526.96 \qquad (3.2\text{-}10)$$

The corresponding I.T.T.C. friction drag coefficient range is:

$$C_f = .075(\log RN - 2)^{-2} = .075\left[\log(RN \times 10^{-6}) + 4\right]^{-2}$$

$$= .0018192 \text{ to } .0016599$$

$$= .0016068 + \frac{.0000531}{C_{L_{40}}} C_L \qquad (3.2\text{-}11)$$

and with a .0005 allowance

$$C_f + C_A = .0021068 + \frac{.0000531}{C_{L_{40}}} C_L \qquad (3.2\text{-}12)$$

This formulation from Reference 16 is employed here. It is compared with the A.T.T.C. formulation and with current GAC practice for pod drag on Figure 3-13.

Referencing the 1649 sq. ft. tank wetted area of Reference 16 to the total foil area, the tank profile drag coefficient becomes:

$$C_{D_{P_T}} = \frac{1649}{238.48}(C_f + C_A) = 6.9146(C_f + C_A)$$

$$= .014568 + \frac{.0003672}{C_{L_{40}}} C_L \qquad (3.2\text{-}13)$$

From Reference 2 to the wave drag coefficients at design speed (40 kts), half-design speed, and half design-speed-ϕ points (ϕ_0/ϕ = 1, 4/3, and 2) are:

$$C_{W_D}' = .000119$$
$$C_{W_{\phi_0/2}} = .00035$$
$$C_{W_{V_0/2}} = .000799 \qquad (3.2\text{-}14)$$

BUOYANCY/FUEL TANK FRICTION DRAG COEFFICIENT

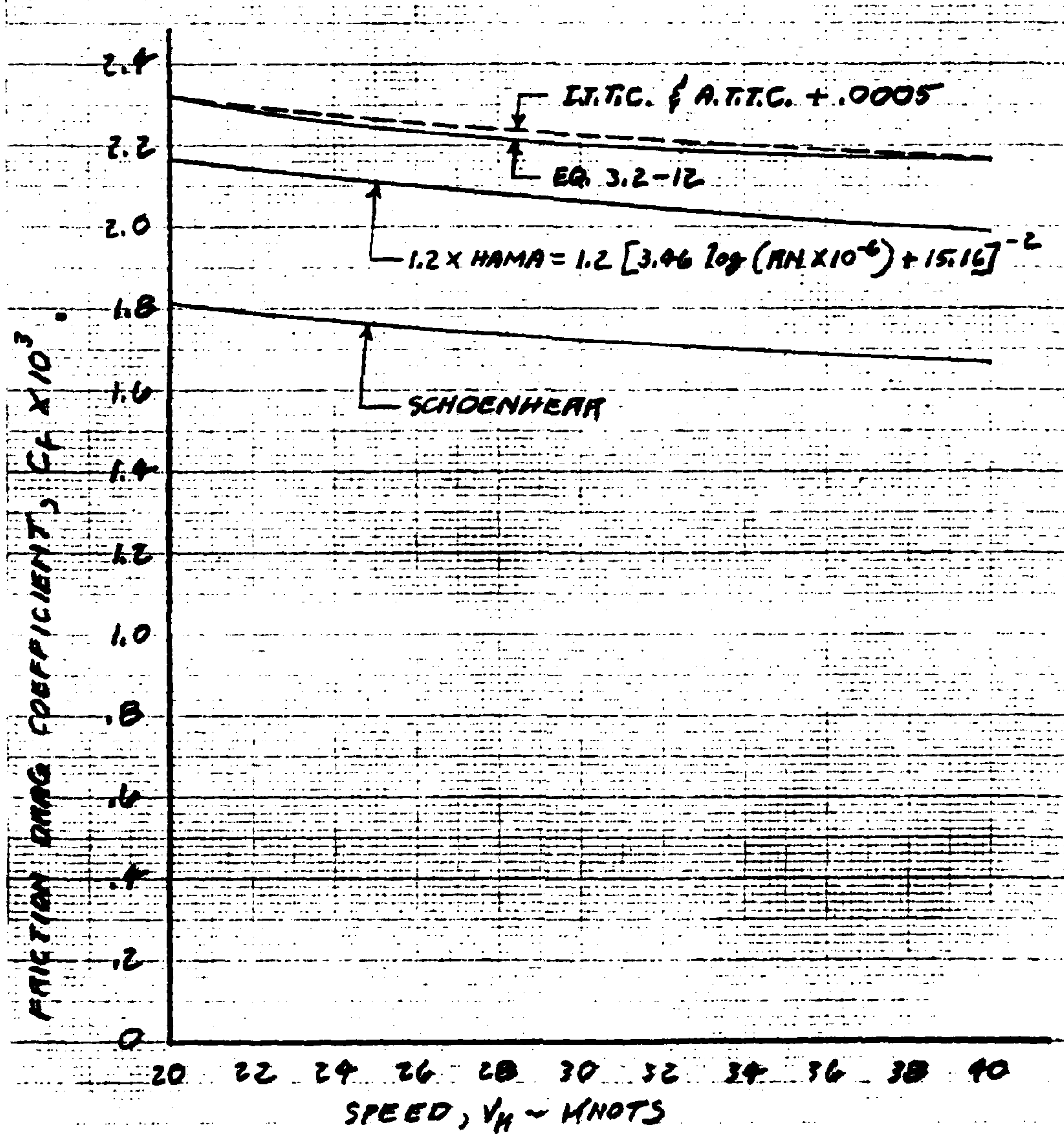


FIGURE 3-13

HRW 9/20/78

3.2 (Cont'd) for which the drag polar form is

$$C_W' = C_{0_W}' + C_{1_W}' C_L + C_{2_W}' C_L^2 \tag{3.2-15}$$

where:

$$C_{0_W}' = \frac{8}{3} C_{W_0}' - 2 C_{W_{\phi_0/2}}' + \frac{1}{3} C_{W_{v_0/2}}' = -.0001163$$

$$C_{1_W}' = \left(-2 C_{W_0}' + \frac{5}{2} C_{W_{\phi_0/2}}' - \frac{1}{2} C_{W_{v_0/2}}'\right) / C_{L_{40}} = .0002375 / C_{L_{40}}$$

$$C_{2_W}' = \left(\frac{1}{3} C_{W_0}' - \frac{1}{2} C_{W_{\phi_0/2}}' + \frac{1}{6} C_{W_{v_0/2}}'\right) / C_{L_{40}}^2 = -.000002167 / C_{L_{40}}^2$$

(3.2-16)

So the drag polar form of the tank wave drag coefficient is:

$$C_W' = -.0001163 + .0002375 \frac{C_L}{C_{L_{40}}} - .000002167 \left(\frac{C_L}{C_{L_{40}}}\right)^2 \tag{3.2-17}$$

Which is compared with the drag coefficients of Reference 16 on Figure 3-14.

Referenced to the craft foil area Equation 3.2-17 becomes:

$$C_W = \frac{S_{wet}}{S} C_W' = 6.9146\, C_W'$$

$$= -.0008042 + .001642 \frac{C_L}{C_{L_{40}}} - .00001498 \left(\frac{C_L}{C_{L_{40}}}\right)^2$$

(3.2-18)

The M169 drag polar then becomes the sum of Equations 3.1-6, 3.2-7, 3.2-9, 3.2-13, and 3.2-18 which is compiled on Figure 3-15. Figure 3-16 shows the composition of the drag increment associated with the tank and Figures 3-17 and 3-18 set that increment into the context of the total craft drag coefficient and drag.

WAVE DRAG COEFFICIENT

BUOYANCY/FUEL TANK

8.75 ft. DEPTH

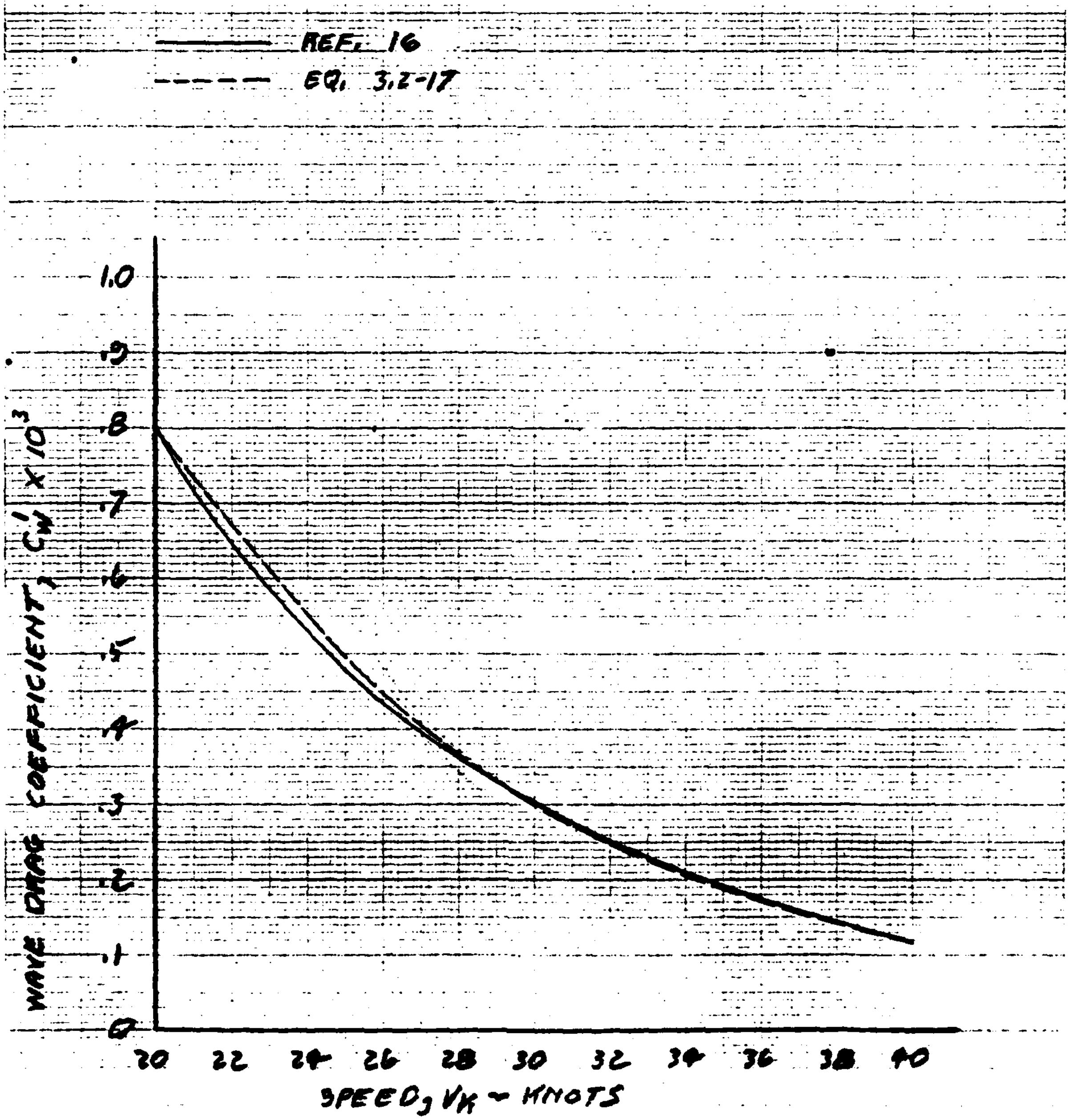


FIGURE 3-14

HRW 9/29/80

M169 CRUISE DRAG POLAR

PCH C_{D_P}: .01284

PCH C_{D_L}: $.00045 + .032076 C^2_{L_{40}} - (.003 + .074238 C_{L_{40}}) C_L + .12970 C_L^2$

Strut C_{D_P}: $.0013694 + \frac{.00005}{C_{L_{40}}} C_L$

Strut $C_{D_{Spray}}$ .0014492

Fin C_{D_P}: $.0015119 + \frac{.0000607}{C_{L_{40}}} C_L$

Tank C_{D_P}: $.014568 + \frac{.0003672}{C_{L_{40}}} C_L$

Tank C_W: $-.0008042 + \frac{.001642}{C_{L_{40}}} C_L - \frac{.00001498}{C^2_{L_{40}}} C_L^2$

$$C_D = .031384 + .032076\, C^2_{L_{40}} - \left(.003 + .074238 C_{L_{40}} - \frac{.00212}{C_{L_{40}}}\right) C_L$$

$$+ \left(.1297 - \frac{.00001498}{C^2_{L_{40}}}\right) C_L^2$$

For L = 117.79 lT , $C_{L_{40}}$ = .24359;

$$C_D = .033287 - .01238 C_L + .12945 C_L^2$$

FIGURE 3-15

PARASITE DRAG COEFFICIENTS

4 ft. DEPTH

NOTE: FOR PCH PARASITE DRAG COMPOSITION SEE FIG. 3-9

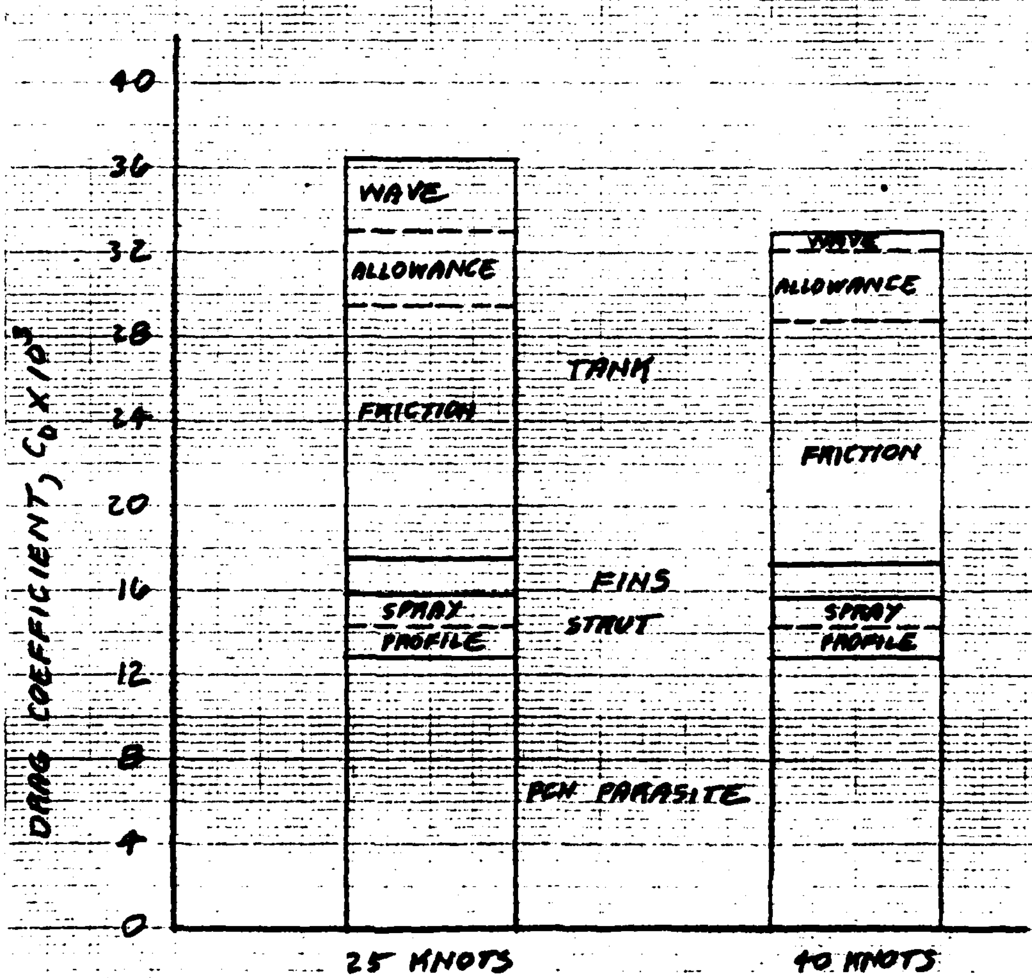


FIGURE 3-16

HRW 9/20/80

DRAG COEFFICIENT COMPOSITION

4 ft. DEPTH

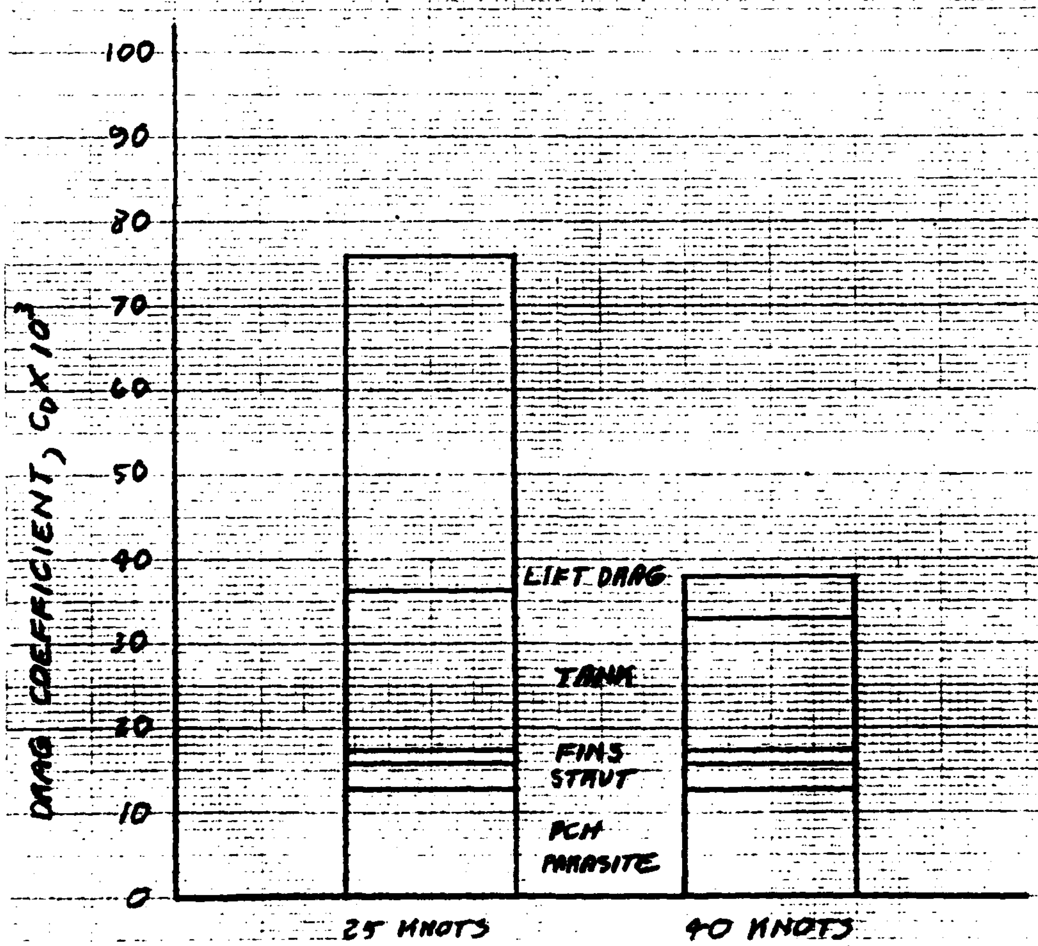


FIGURE 3-17

HRW 9/20/80

DRAG COMPOSITION

4 ft. DEPTH

$L_D = 117.79$ L.T.

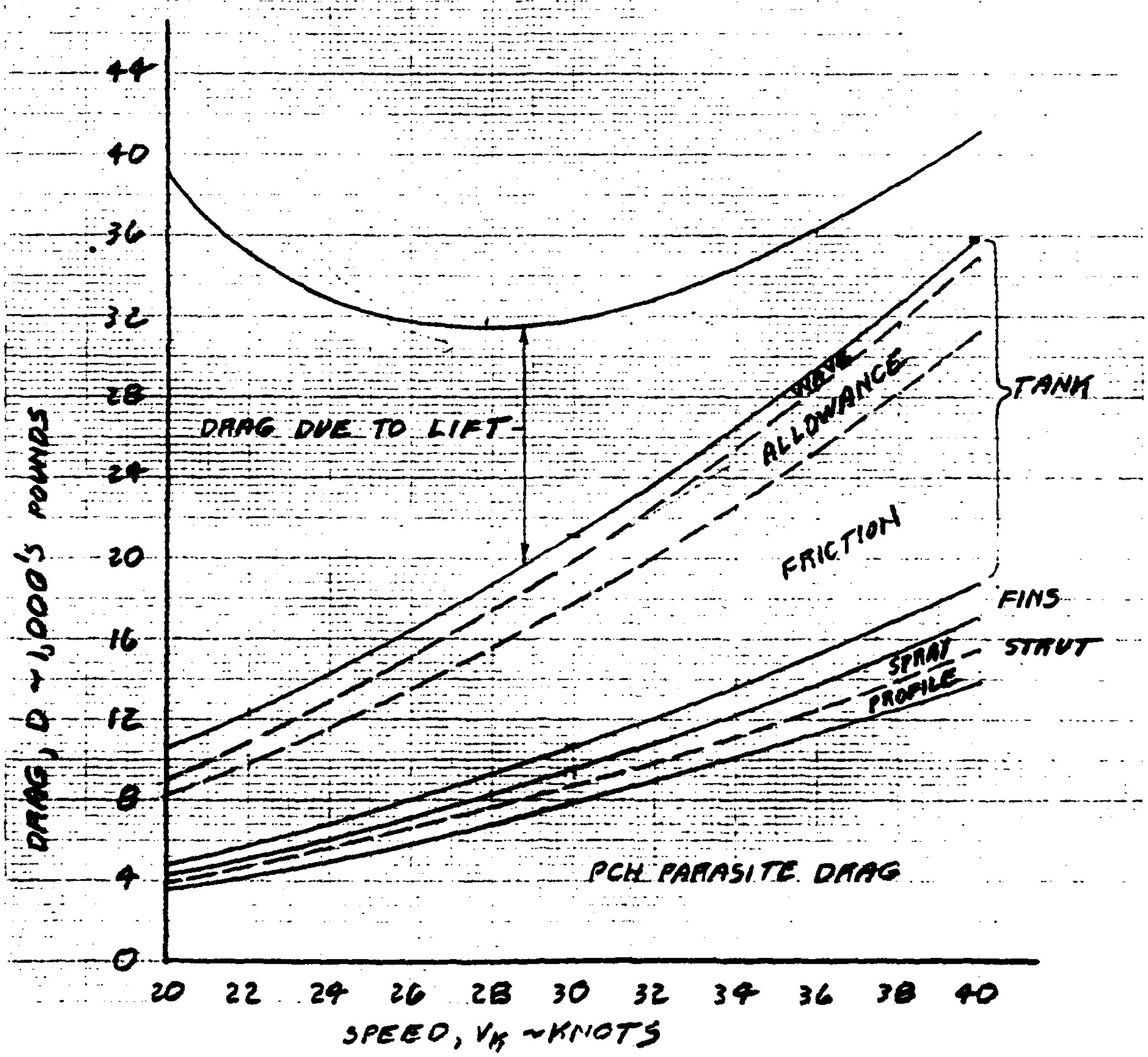


FIGURE 3-18

HRW 9/20/70

3.3 PCH Take Off Drag Polar - The PCH take off drag polar of Reference 1 is employed in the form of Equation 3.3.7 of Reference 17.

$$C_D = .016939 - .00319\, C_{L_{30}}^2 - (.003 + .0169\, C_{L_{30}})\, C_L + .10203\, C_L^2 \tag{3.3-1}$$

Note that the zero displacement hull spray drag coefficient is not included.

3.4 M169 Take Off Drag Polar - From Reference 2 the tank wave drag coefficients at 16.16 ft. depth and at 15, 21.213, and 30 knots (q_D/q = 1, 2, and 4) are:

$$\begin{aligned} C'_{W_D} &= .000129 \\ C'_{W_{q_D/2}} &= .00036 \\ C'_{W_{v_D/2}} &= .000231 \end{aligned} \tag{3.4-1}$$

For which the drag polar form is:

$$C'_W = C'_{0_W} + C'_{1_W}\, C_L + C'_{2_W}\, C_L^2 \tag{3.4-2}$$

where

$$\begin{aligned} C'_{0_W} &= \tfrac{8}{3} C'_{W_D} - 2\, C'_{W_{q_D/2}} + \tfrac{1}{3} C'_{W_{v_D/2}} &&= -.0002990 \\ C'_{1_W} &= \left(-2 C'_{W_D} + \tfrac{5}{2} C'_{W_{q_D/2}} - \tfrac{1}{2} C'_{W_{v_D/2}}\right) \Big/ C_{L_{30}} &&= .0005265 \\ C'_{2_W} &= \left(\tfrac{1}{3} C'_{W_D} - \tfrac{1}{2} C'_{W_{q_D/2}} + \tfrac{1}{6} C'_{W_{v_D/2}}\right) \Big/ C_{L_{30}}^2 &&= -.0000985 \end{aligned} \tag{3.4-3}$$

so the drag polar form of the tank wave drag is:

$$C'_W = -.000299 + .0005265 \frac{C_L}{C_{L_{30}}} - .0000985 \left(\frac{C_L}{C_{L_{30}}}\right)^2 \tag{3.4-4}$$

3.4 (Cont'd) which is compared with the drag coefficients of Reference 16 on Figure 3-19 . Referenced to the craft foil area Equation 3.2-17 becomes:

$$C_W = \frac{S_{WETT}}{S} C_W' = 6.9146\, C_W'$$
$$= -.002068 + .00364 \frac{C_L}{C_{L_{30}}} - .0006811 \left(\frac{C_L}{C_{L_{30}}}\right)^2 \tag{3.4-5}$$

In the 15-30 knot range the tank Reynolds Number range is:

$$RN \times 10^{-6} = \frac{1.6889 \times 100 V_M}{12.82} = 197.61 \text{ to } 395.22 \tag{3.4-6}$$

The corresponding I.T.T.C friction drag coefficient range is:

$$C_f = .075 \left[\log (RN \times 10^{-6}) + 4\right]^{-2}$$
$$= .0018922 \text{ to } .0017234$$
$$= .0016671 + \frac{.00005627}{C_{L_{30}}} C_L \tag{3.4-7}$$

and with a .0005 allowance:

$$C_f + C_A = .0021671 + \frac{.00005627}{C_{L_{30}}} C_L \tag{3.4-8}$$

Referenced to the foil area the tank profile drag coefficient becomes:

$$C_{DP_T} = 6.9146 \left(C_f + C_A\right)$$
$$= .014985 + \frac{.0003891}{C_{L_{30}}} C_L \tag{3.4-9}$$

For the lower 6 ft. of the strut the Reynolds Number range is:

$$RN \times 10^{-6} = \frac{1.6889 \times 10 V_M}{12.82} = 19.761 \text{ to } 39.522 \tag{3.4-10}$$

WAVE DRAG COEFFICIENT

BUOYANCY/FUEL TANK

16.16 ft. DEPTH

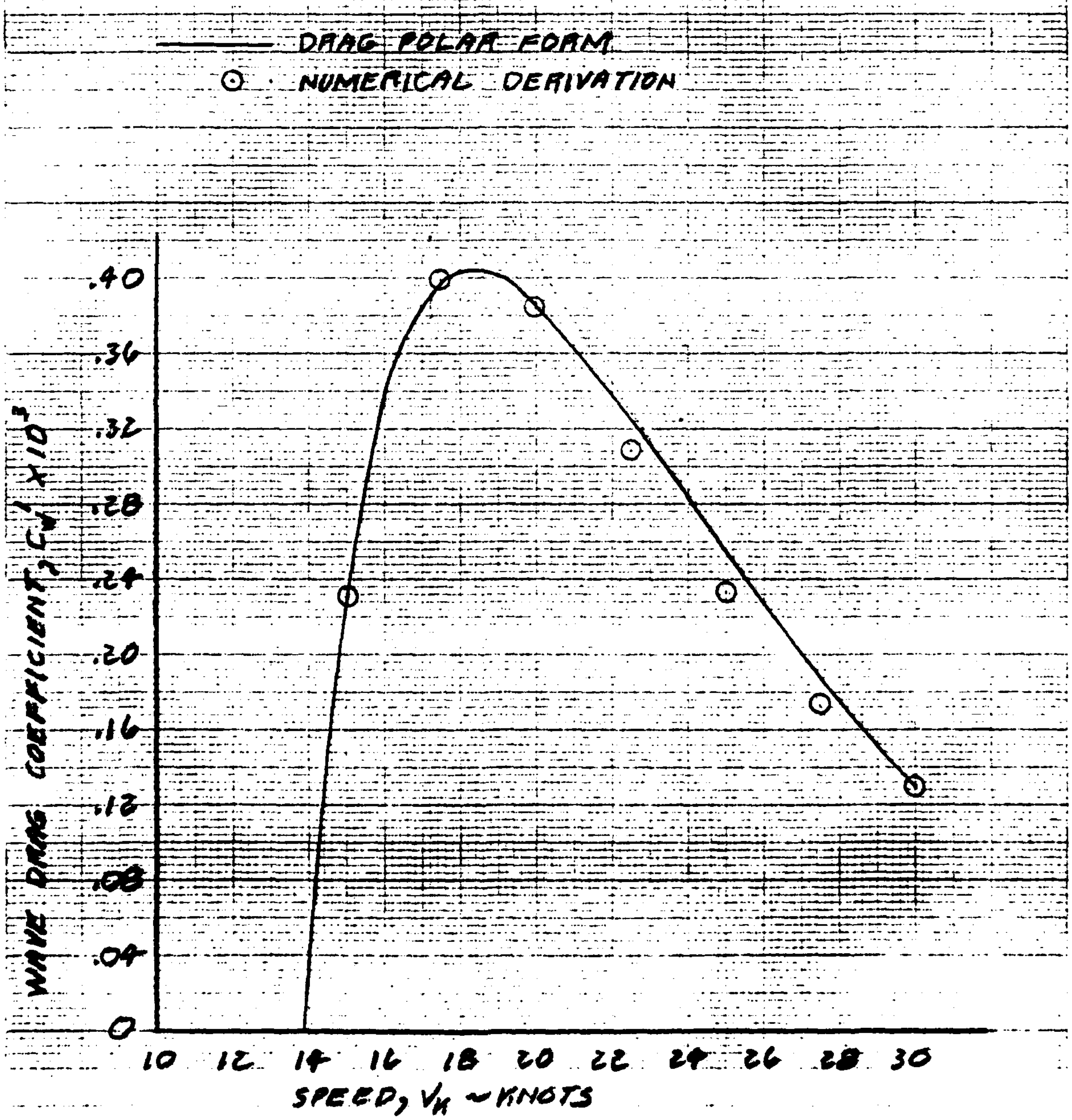


FIGURE 3-19

HAW 9/21/80

3.4 The friction coefficient range is:
(Cont'd)

$$C_f = \left[3.46 \log\left(RN \times 10^{-6}\right) + 15.16\right]^{-2} \tag{3.4-11}$$

$$= .0025916 \text{ to } .0023372$$

which may be written

$$C_f = .0022524 + \frac{.0000842}{C_{L_{30}}} C_L \tag{3.4-12}$$

From Equation 3.2-4 and referenced to the craft foil area the drag coefficient for the lower 6 ft. of the strut is:

$$C_{D_{S_1}} = \frac{6 \times 10}{238.48} \times 2.7456\, C_f = .69078\, C_f$$

$$= .0015559 + \frac{.00005858}{C_{L_{30}}} C_L \tag{3.4-13}$$

The average chord for the upper half of the tank strut is 13.5 ft. and the Reynolds Number range is:

$$RN \times 10^{-6} = \frac{1.6889 \times 13.5\, V_K}{12.82} = 26.677 \text{ to } 53.354 \tag{3.4-14}$$

The friction drag coefficient is:

$$C_f = \left[3.46 \log\left(RN \times 10^{-6}\right) + 15.16\right]^{-2}$$

$$= .0024766 \text{ to } .0022385$$

$$= .0021591 + \frac{.00007937}{C_{L_{30}}} C_L \tag{3.4-15}$$

Then the profile drag coefficient for the upper 6.5 ft. of the strut is:

$$C_{D_{S_2}} = \frac{6.5 \times 13.5}{238.48} \times 2.7456\, C_f = 1.0103\, C_f$$

$$= .0021812 + \frac{.00008019}{C_{L_{30}}} C_L \tag{3.4-16}$$

3.4 (Cont'd) and the total tank strut profile drag coefficient is the sum of Equations 3.4-13 and 3.4-16:

$$C_{D_{Sp}} = .0037371 + \frac{.00013877}{C_{L_{30}}} C_L \quad (3.4\text{-}17)$$

Referenced to the craft foil area the tank strut spray drag employed is:

$$C_{D_{spray_{strut}}} = .24\left(\frac{t}{c}\right)^2 \frac{c^2}{S}$$

$$= .24(.12)^2 \frac{(17)^2}{238.48}$$

$$= .0041881 \quad (3.4\text{-}18)$$

Note here that the .0036236 hull spray drag coefficient of Equation 3.3-16 of Reference 17 applies when keel kissing but the larger strut spray drag coefficient is taken here as characteristic of the take off.

Through the take-off, the fin Reynolds Number range is:

$$RN \times 10^{-6} = \frac{1.6889 \times 3.5 V_K}{12.82} = 6.9163 \text{ to } 13.833 \quad (3.4\text{-}19)$$

and the C_f range is:

$$C_f = \left[3.46 \log(RN \times 10^{-6}) + 15.16\right]^{-2}$$

$$= .0030639 \text{ to } .002739$$

$$= .0026307 + \frac{.00010831}{C_{L_{30}}} C_L \quad (3.4\text{-}20)$$

Then from Equation 3.2-9 the fin profile drag coefficient is:

$$C_{D_{fin}} = .60040\ C_f$$

$$= .0015795 + \frac{.00006503}{C_{L_{30}}} C_L \quad (3.4\text{-}21)$$

3.4 (Cont'd) The M169 take-off drag polar then becomes the sum of Equations 3.3.-1, 3.4 -5, 3.4-9, 3.4-17, 3.4-18, and 3.4-21 which is compiled in Figure 3-20.

M169 TAKE OFF DRAG POLAR

PCH C_D: $.016939 - .00319\, C_{L_{30}}^2 - (.003 + .0169 C_{L_{30}})\, C_L + .10203 C_L^2$

Strut C_{D_P}: $.0037371 + \dfrac{.00013877 C_L}{C_{L_{30}}}$

Strut $C_{D_{Spray}}$: $.0041881$

Fin C_{D_P}: $.0015795 + \dfrac{.00006503 C_L}{C_{L_{30}}}$

Tank C_{D_P}: $.014985 + \dfrac{.0003891 C_L}{C_{L_{30}}}$

Tank C_W: $-.002068 + \dfrac{.00364 C_L}{C_{L_{30}}} - \dfrac{.0006811}{C_{L_{30}}^2}\, C_L^2$

$$C_D = .039361 - .00319 C_{L_{30}}^2 - \left(.003 + .0169 C_{L_{30}} - \frac{.0042329}{C_{L_{30}}}\right) C_L + \left(.10203 - \frac{.0006811}{C_{L_{30}}^2}\right) C_L^2$$

For L = 117.79 L.T., $C_{L_{30}} = .43306$

$C_D = .038763 - .00054432 C_L + .098398 C_L^2$

FIGURE 3-20

3.5 Propulsion and Performance - The propulsion system on the PCH-1 Mod 1 consists of two Proteus PT 1273 gas turbine engines, each rated at 4110 HP at maximum power, driving two fixed pitch five bladed subcavitating propellers each. The transmission consists of a reduction gear box integral with the engine, a disconnect coupling between the gear box and the strut, upper and lower bevel gear boxes in the strut and pod, with associated strut and Propeller shafting. Overall gear reduction between the engine and the propeller is 3.37:1. The propeller operational speed is 1500 RPM.

The propulsion system was investigated in various degrees of detail, based in part on the resource information available from DTNSRDC and HYSTU.

No change in the existing Proteus gas turbine engine installation is contemplated. Performance characteristics are combined with the propeller and are presented herein.

Propeller performance has been estimated from PCH-1 Mod 1 foilborne test data, supplied by HYSTU and DTNSRDC. Although there are reservations about the accuracy of the measured data (particularly thrust), the resultant propeller coefficients and efficiency appear reasonable.

3.5.1 Referencing Section 5.0, the net buoyancy of the buoyancy/fuel tank is + 3.57 L.T. in the full fuel foad condition and -5.25 L.T. with the fuel transferred out of the tank and replaced by water ballast. Figure 3-21 presents one way of varying the buoyancy of the tank with fuel burn-off. With the hull fuel burned off first, the net tank buoyancy of + 3.57 L.T. is constant for the first 19.4 L.T. of the fuel burn-off, which is the total usable fuel within the hull. The most simplistic way of representing the variation of tank buoyancy with fuel burn-off is to assume a linear relationship as shown in Figure 3-21.

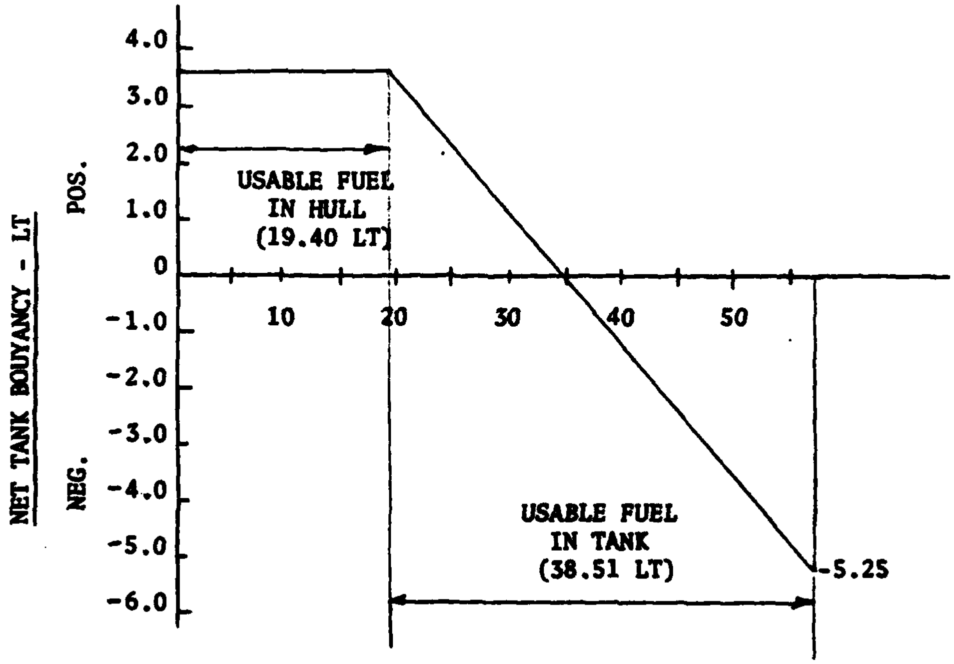
Assuming the linear relationship between buoyancy and fuel burn-off in the tank, the variation of dynamic lift with fuel burn-off is also linear and is shown in Figure 3-22.

VARIATION OF NET TANK BOUYANCY WITH FUEL BURN-OFF

FUEL IN HULL BURNED OFF FIRST

TOTAL FUEL=HULL, 20 LT + TANK, 40.32 LT = 60.32 LT

TOTAL USABLE FUEL = HULL + TANK = 57.91 LT



FUEL BURN-OFF

FIGURE 3-21

DESIGN NO.	SUBJECT			WBS
M-169				
ANALYST	CHECKER	ANALYSIS DATE		PAGE NO.

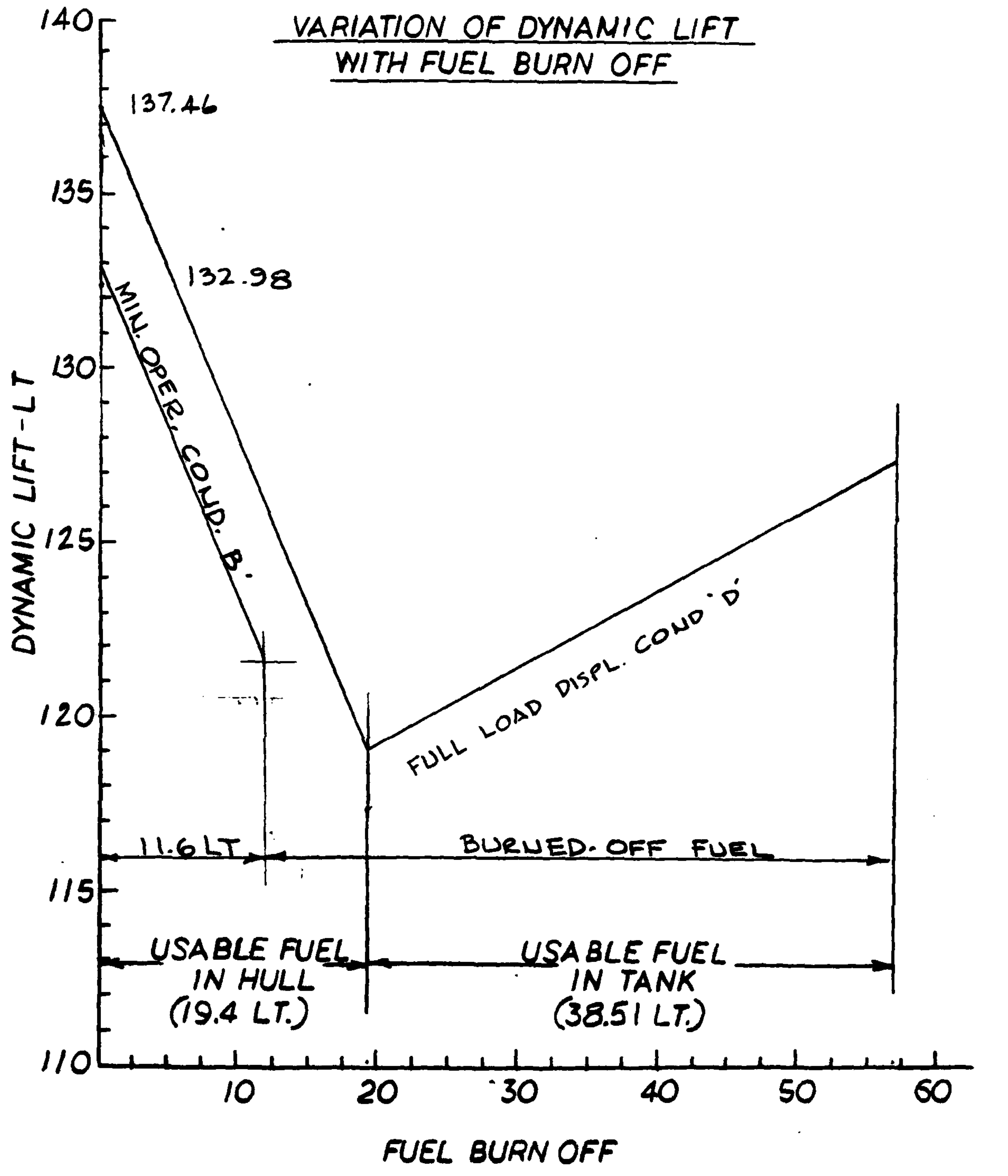


FIGURE 3-22

3.5.1 (Cont'd) Fuel flow characteristics of the Proteus engine as measured in foilborne tests are shown in Figure 3-23 as a function of propeller horsepower. The matched fuel flow rates and ship speeds produce the ship specific range (SR) characteristics, as shown in Figure 3-24 where:

$$SR = \frac{(V)\ (2240)}{W_f} = (\text{N.M./L. Ton of Fuel})$$

Where: V = Ship Speed, (Knots)
W_f = Total Fuel Flow, (Lbs./Hr.)

Total maximum range of Design M169 is obtained by integration of the maximum specific range vs. usable fuel load curves of Figure 3-25 resulting in approximately 1100 N.MI. of range, with continuous fuel transfer at the engine consumption rate after the hull tank fuel has been burned-off. A more realistic mode of operation is to transfer fuel in discrete steps to re-fill the hull tanks when a minimum level ($\approx$ 3 L.Tons) in these tanks has been reached. Complete fuel transfer can be accomplished in two operations as indicated in Figure 3-25. The corresponding range for the two segment discrete fuel transfer is about 1070 N.MI. The lower range is due to the higher drag (higher dynamic lift) and corresponding lower specific range (SR) throughout the operating range.

Figure 3-26 shows the dynamic lift required as a function of usable fuel on-board for the two methods of fuel transfer discussed for Figure 3-25. Dynamic lift decreases with fuel burn-off until fuel is transferred from the buoyancy/fuel tank to the hull, at which time the dynamic lift increases as an equal volume of heavier sea water ballast replaces the transferred fuel. The manner and rate at which the fuel is transferred will affect the shape of the specific range vs. fuel load curve of Figure 3-25 thus changing the total absolute range.

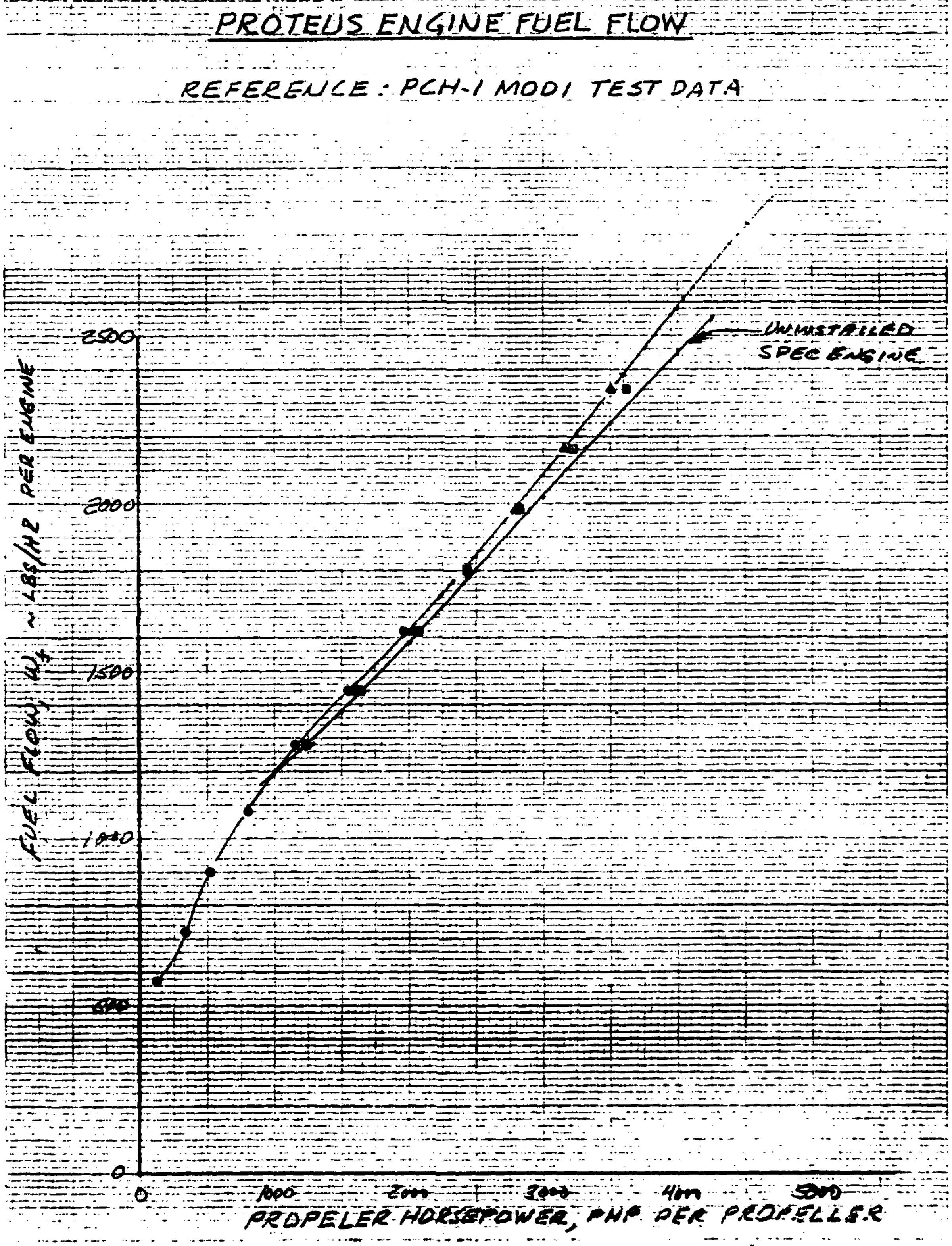

PROTEUS ENGINE FUEL FLOW
REFERENCE: PCH-1 MOD1 TEST DATA
FUEL FLOW, W_f ~ LBS/HR PER ENGINE
2500
2000
1500
1000
500
0
0
1000
2000
3000
4000
5000
PROPELER HORSEPOWER, PHP PER PROPELLER
UNINSTALLED
SPEC ENGINE

FIGURE 3-23

M169 SPECIFIC RANGE

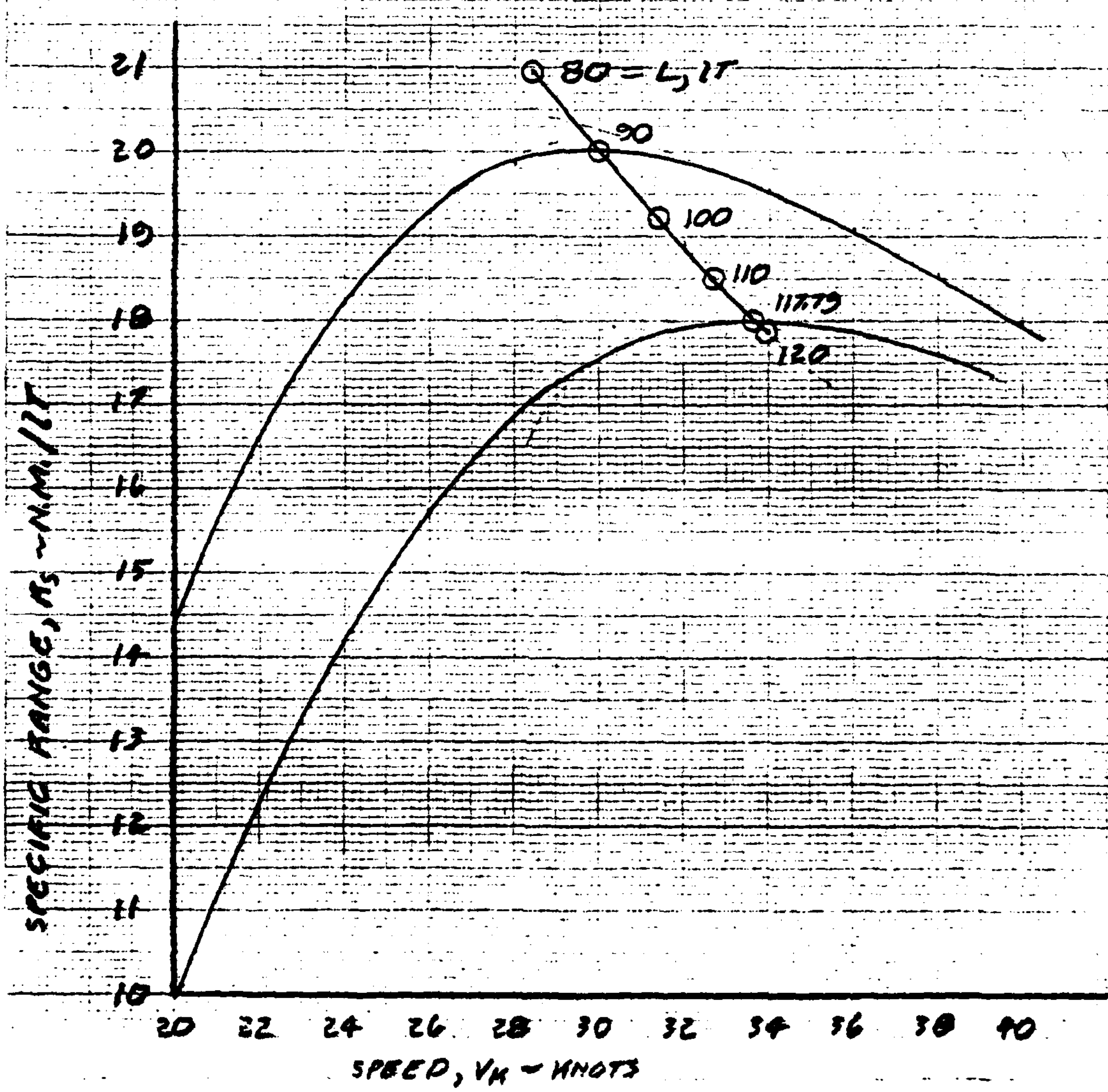
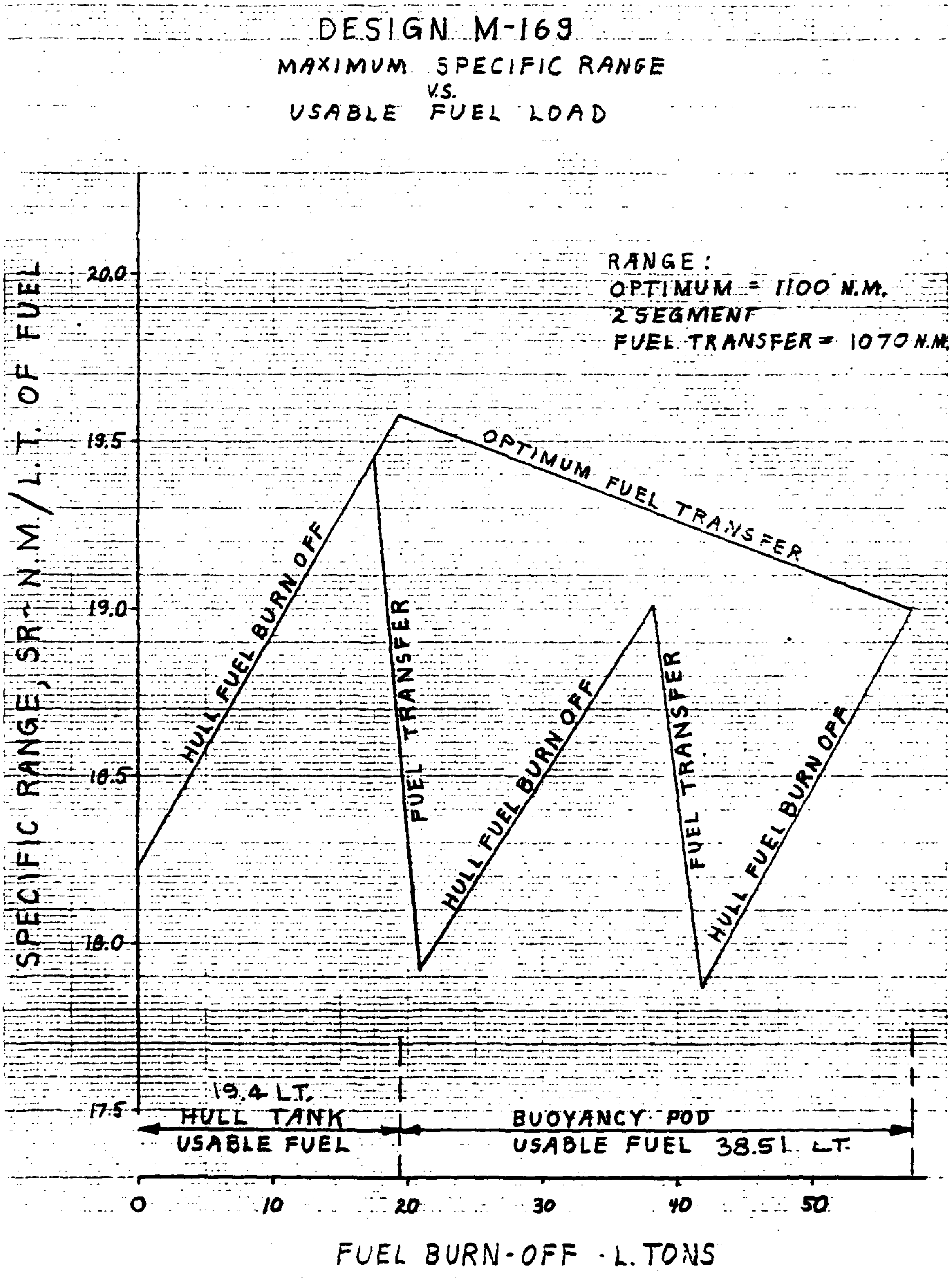
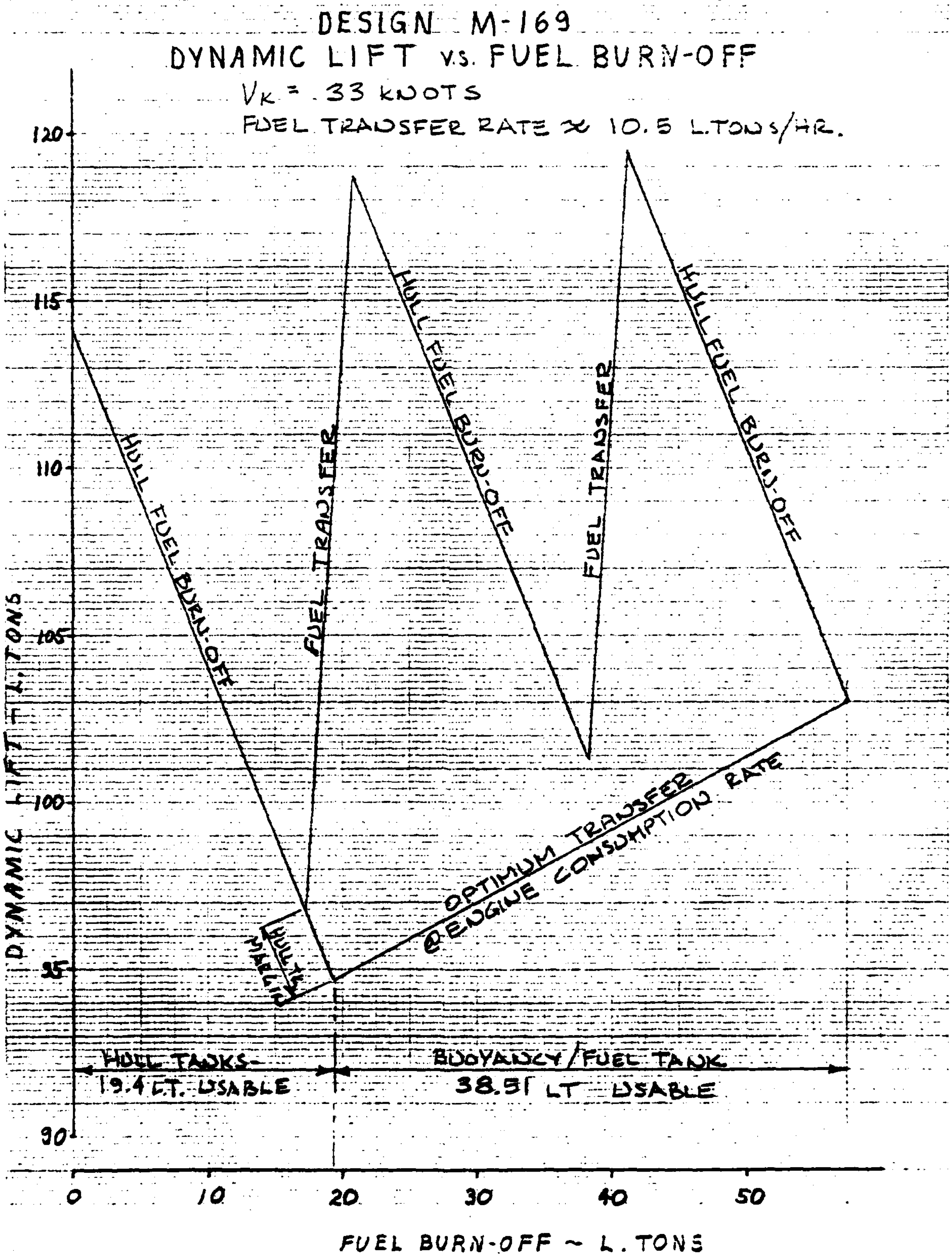


FIGURE 3-24



DESIGN M-169
MAXIMUM SPECIFIC RANGE
V.S.
USABLE FUEL LOAD
RANGE:
OPTIMUM = 1100 N.M.
2 SEGMENT
FUEL TRANSFER = 1070 N.M.
OPTIMUM FUEL TRANSFER
HULL FUEL BURN OFF
FUEL TRANSFER
HULL FUEL BURN OFF
FUEL TRANSFER
HULL FUEL BURN OFF
SPECIFIC RANGE, SR - N.M./L.T. OF FUEL
20.0
19.5
19.0
18.5
18.0
17.5
19.4 L.T.
HULL TANK
USABLE FUEL
BUOYANCY POD
USABLE FUEL 38.51 L.T.
0
10
20
30
40
50
FUEL BURN-OFF · L.TONS

FIGURE 3-25

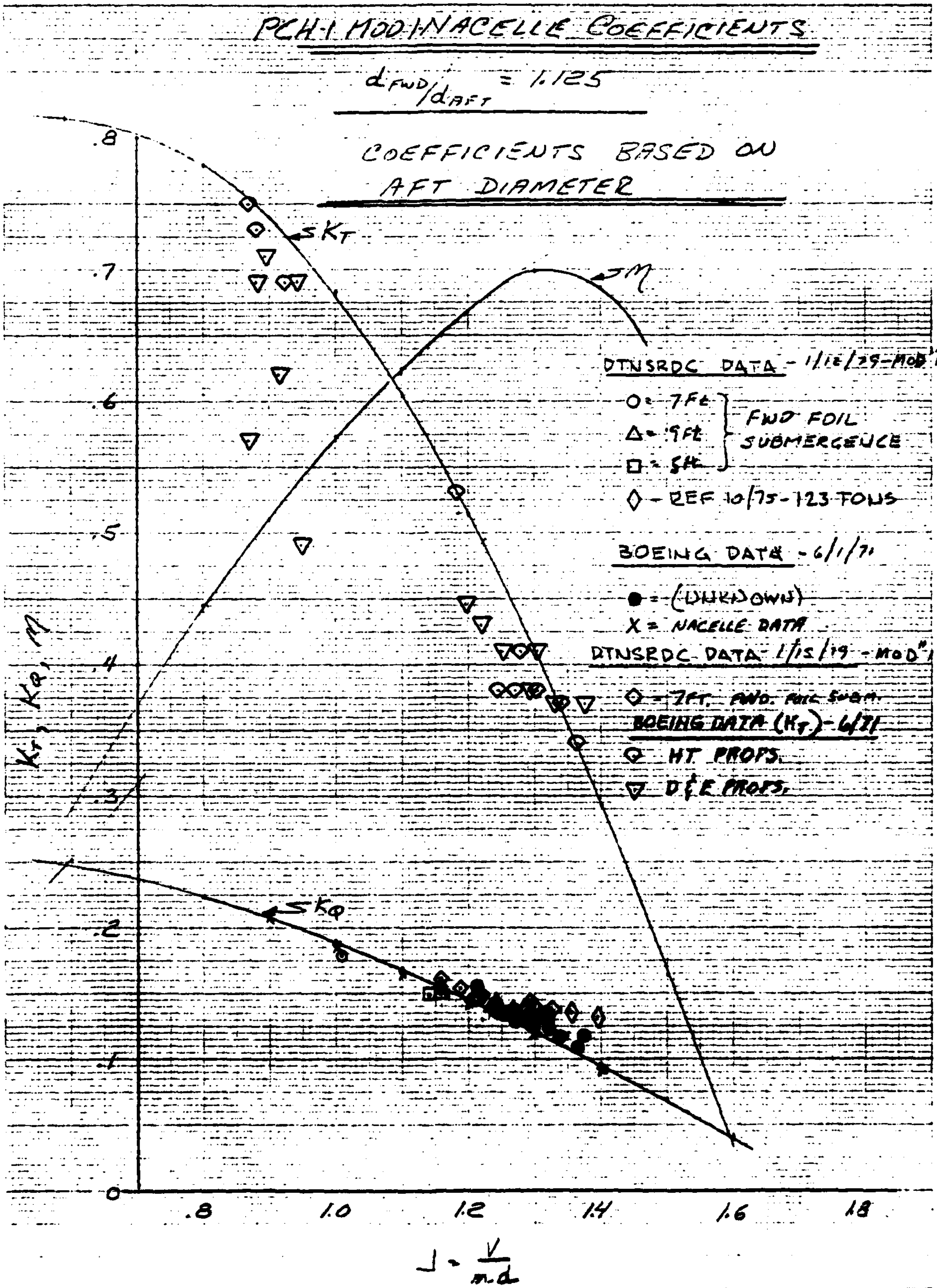


DESIGN M-169
DYNAMIC LIFT vs. FUEL BURN-OFF
V_K = 33 KNOTS
FUEL TRANSFER RATE ≈ 10.5 L.TONS/HR.
DYNAMIC LIFT ~ L. TONS
120
115
110
105
100
95
90
HULL FUEL BURN-OFF
FUEL TRANSFER
HULL FUEL BURN-OFF
FUEL TRANSFER
HULL FUEL BURN-OFF
OPTIMUM TRANSFER
@ENGINE CONSUMPTION RATE
HULL TK MARGIN
HULL TANKS-
19.4 L.T. USABLE
BUOYANCY/FUEL TANK
38.51 LT USABLE
0
10
20
30
40
50
FUEL BURN-OFF ~ L. TONS

FIGURE 3-26

3.5.2 Performance - Combining the hydrodynamic and propulsion characteristics presented in Sections 3.1 and 3.9, the following performance estimates are derived for the M169 design.

The deduced propeller coefficients are shown in Figures 3-27. Because of the limited data available, the propeller performance is described by single lines for K_T and K_Q which presumes that the propeller is completely wetted (subcavitated) throughout its operating range. <u>The validity of this assumption is not known</u>, and should be further assessed. Assuming, however, that 46 knots was the limit for fully wetted operation of PCH-1 Mod 1, then the lowest demonstrated local blade cavitation number is $\overline{\sigma_B} = 0.112$. Using the matched propeller advance ratios for Design M169, the maximum ship speed for cavitation free operation of the propeller is estimated to be about 42 knots, as shown in Figure 3-28.



PCH-1 MOD-1 NACELLE COEFFICIENTS
$d_{FWD}/d_{AFT} = 1.125$
COEFFICIENTS BASED ON AFT DIAMETER
K_T
η
K_Q
K_T, K_Q, η
DTNSRDC DATA - 1/15/79 - MOD "1"
○ = 7 Ft
△ = 9 Ft
□ = 5 Ft
FWD FOIL SUBMERGENCE
◇ - REF 10/75 - 123 TONS
BOEING DATA - 6/1/71
● = (UNKNOWN)
X = NACELLE DATA
DTNSRDC DATA 1/15/79 - MOD "1"
◇ = 7 FT. FWD. FOIL SUBM.
BOEING DATA (K_T) - 6/71
HT PROPS.
D & E PROPS.
.8
.7
.6
.5
.4
.3
.2
.1
0
.8
1.0
1.2
1.4
1.6
1.8
$J = \frac{V}{n d}$

FIGURE 3-27

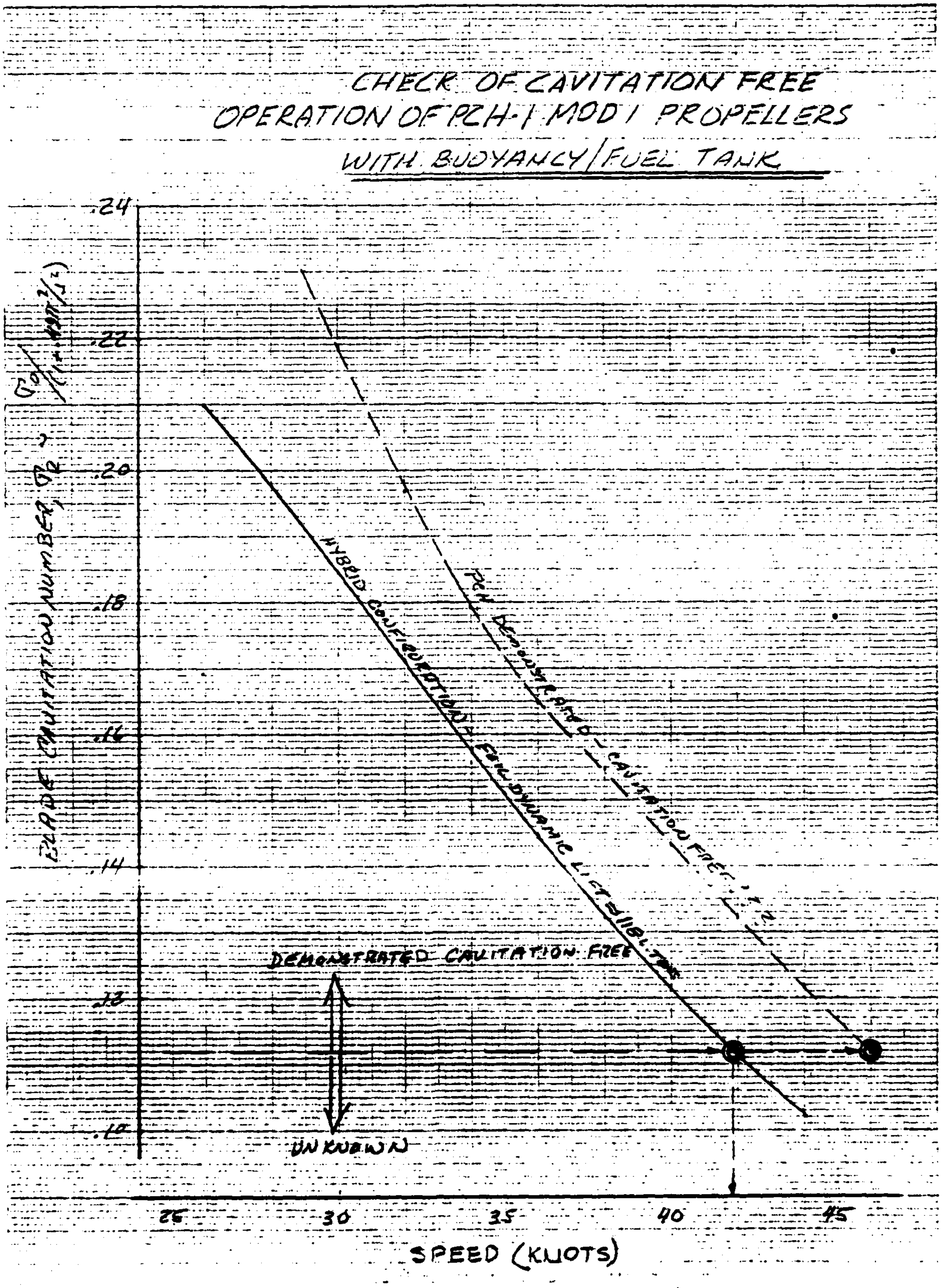

CHECK OF CAVITATION FREE
OPERATION OF PCH-1 MOD 1 PROPELLERS
WITH BUOYANCY/FUEL TANK
.24
.22
.20
.18
.16
.14
.12
.10
25
30
35
40
45
SPEED (KNOTS)
DEMONSTRATED CAVITATION FREE
UNKNOWN
HYBRID CONFIGURATION - FOIL DYNAMIC LIFT = 118L TONS

FIGURE 3-28

3.5.3 Propulsion and Performance - Reference 18 transforms the propeller chart of Figure 3-27 into C_T - C_P form to eliminate the necessity for graphic or computer solution of the propulsion - drag polar match. In C_T - C_P form the propeller (nacelle) map is related to the craft drag polar by the power polar of Figure 20 of Reference 18 which has the equation:

$$C_P = .28386 \frac{\sqrt{1+C_T} + .76143}{\sqrt{1+C_T} - 1} C_T^2 + .11042 \qquad (3.5\text{-}1)$$

where $C_P = P/qAVN$ (N is number of nacelles)

$$C_T = T/qA = \frac{S}{A} C_D$$

$$\eta = C_T/C_P$$

RPM characteristics are given by the J-C_S chart of Figure 29 of Reference 18. The RPM characteristics do not impact M169 performance in any way and are not presented here.

From Equation (45) of Reference 18 the cruise horsepower requirement is given by:

$$BHP_{cr} = C_P V_K^3 / 24.091$$

$$\text{where: } C_P = \frac{C_T}{\eta_I} + .28386 C_T^2 + .11042$$

$$\eta_I = \frac{2}{C_T}\left(\sqrt{1+C_T} - 1\right)$$

$$C_T = 26.358 C_D$$

$$C_D = C_0 + C_1 C_L + C_2 C_L^2$$

$$C_L = 3.30886\, L_{IT}/V_K^2$$

$$\eta = C_T/C_P \qquad (3.5\text{-}2)$$

Figure 3-29 depicts the propeller cruise efficiency for the Design M169.

MIG9 CRUISE PROPELLER EFFICIENCY

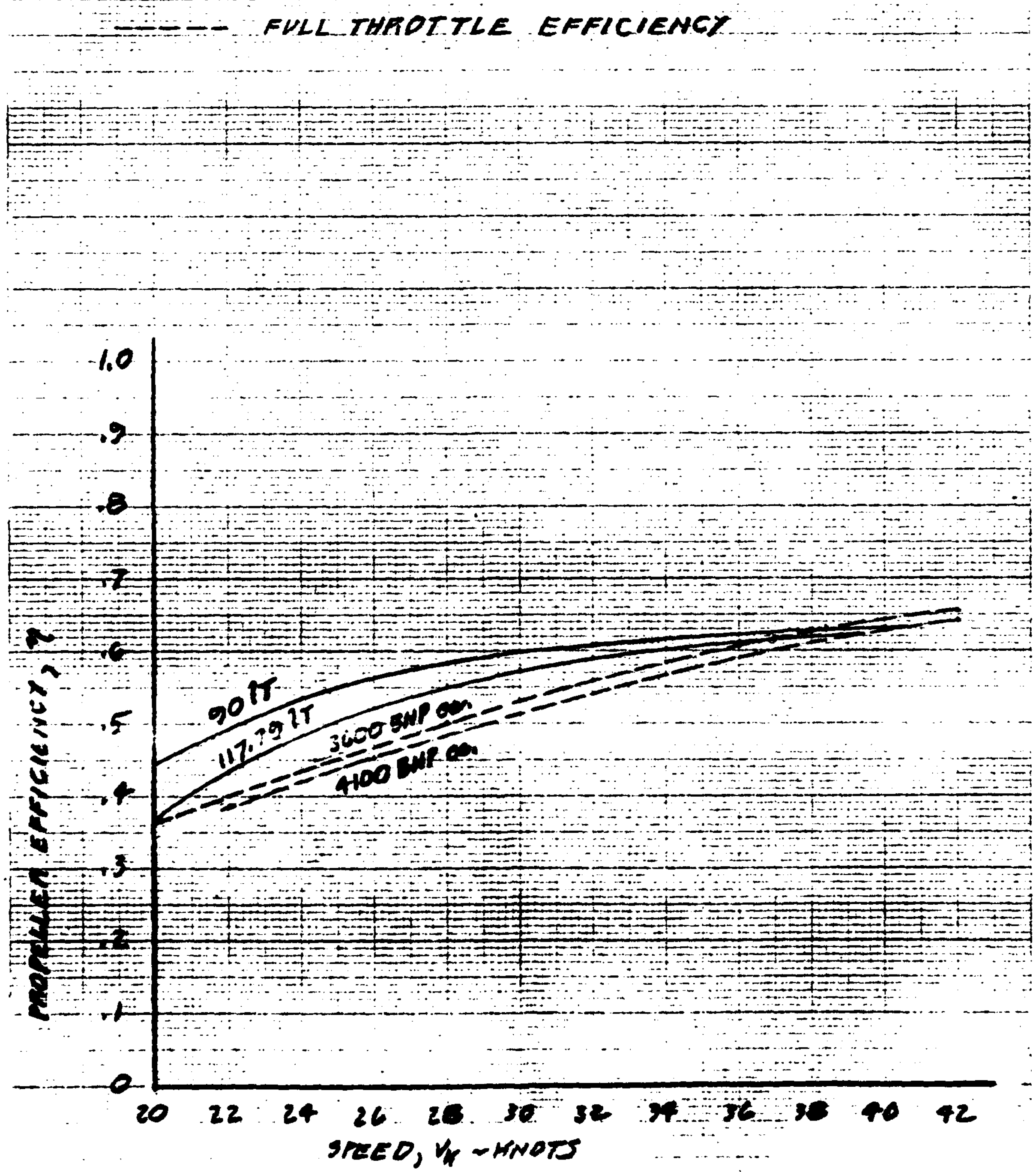


FIGURE 3-29

NRW 9/22/80

3.5.3 (Cont'd) This power requirement is shown on Figure 3-30 for two weights for the drag polar of Figure 3-15. Top speeds are obtained by setting Equation 3.5-2 equal to the power available and are shown on Figure 3-31 over a range of dynamic lifts for the rated maximum and continuous powers.

Equations (58) - (61) of Reference 18 give the M169 specific range and endurance as:

$$R_S = \frac{518.76}{\sqrt{L_{IT}}} \frac{\sqrt{C_L}}{C_P^{2/3}}$$

$$E_S = \frac{285.19}{L_{IT}} \frac{C_L}{C_P^{2/3}} = R_S / V_K \qquad (3.5\text{-}3)$$

where
$$C_L = 3.30886\, L_{IT}/V_K^2$$
$$C_T = 26.358\, C_D = 26.358\,(C_0 + C_1 C_L + C_2 C_L^2)$$
$$C_P = \frac{C_T}{\eta_I} + .28386\, C_T^2 + .11042$$
$$\eta_I = \frac{2}{C_T}\left(\sqrt{1+C_T} - 1\right)$$

Figures 3-24 and 3-32 show the variation of specific range and endurance with speed for two dynamic lifts, and the variation of maximum specific range and endurance with their corresponding craft speeds over a range of dynamic lifts. The maximum endurance speed is the minimum power requirement speed and the minimum power stabilized speed.

Equation (49) of Reference 18 gives the M169 take off margin as:

$$M = \frac{C_T / C_D}{26.358} \qquad (3.5\text{-}4)$$

where:
$$C_P = 24.091 \frac{BHP}{V_K^3} = \frac{C_T}{\eta_I} + .28386\, C_T^2 + .11042$$
$$\eta_I = \frac{2}{C_T}\left(\sqrt{1+C_T} - 1\right)$$
$$C_D = C_0 + C_1 C_L + C_2 C_L^2 \qquad \text{(for take off drag polar)}$$
$$C_L = 3.30886\, L_{IT}/V_K^2$$

M169 HORSEPOWER REQUIRED AND AVAILABLE

CRUISE

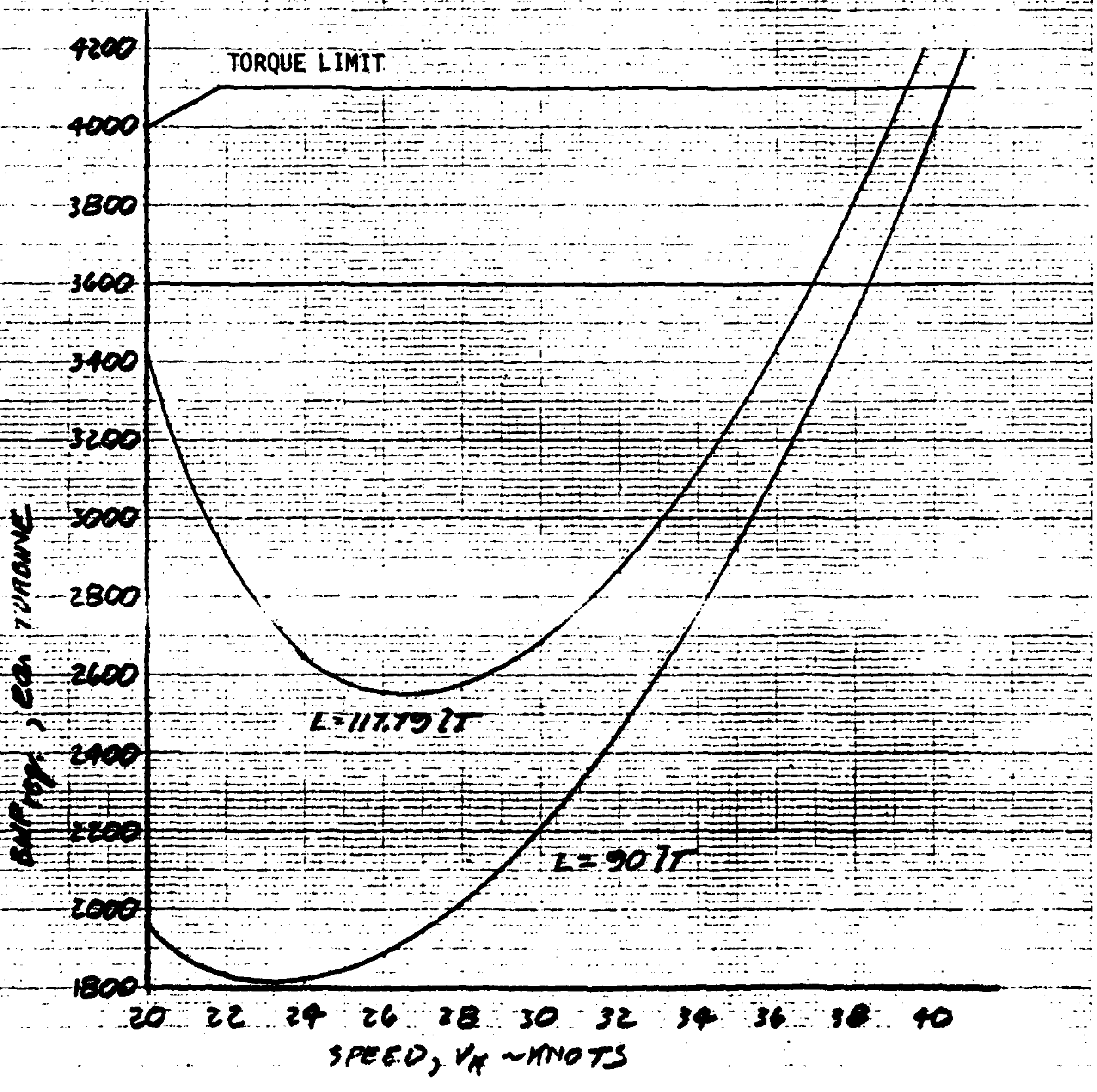


FIGURE 3-30

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M169 TOP SPEED

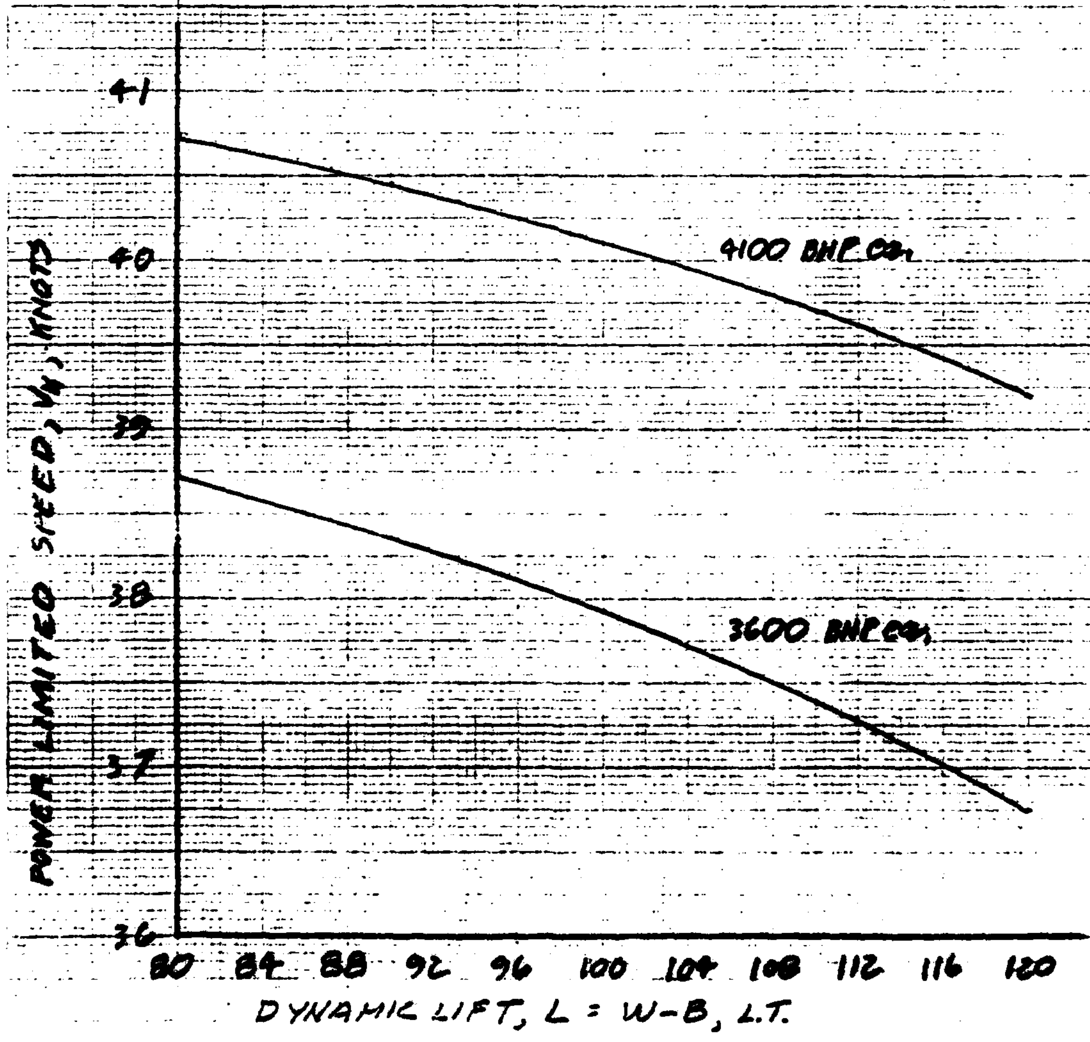


FIGURE 3-31

NEW 9/20/80

MIG9 SPECIFIC ENDURANCE

NOTE: SPEED FOR MAX. E_S IS MIN. POWER STABILIZED FLIGHT SPEED.

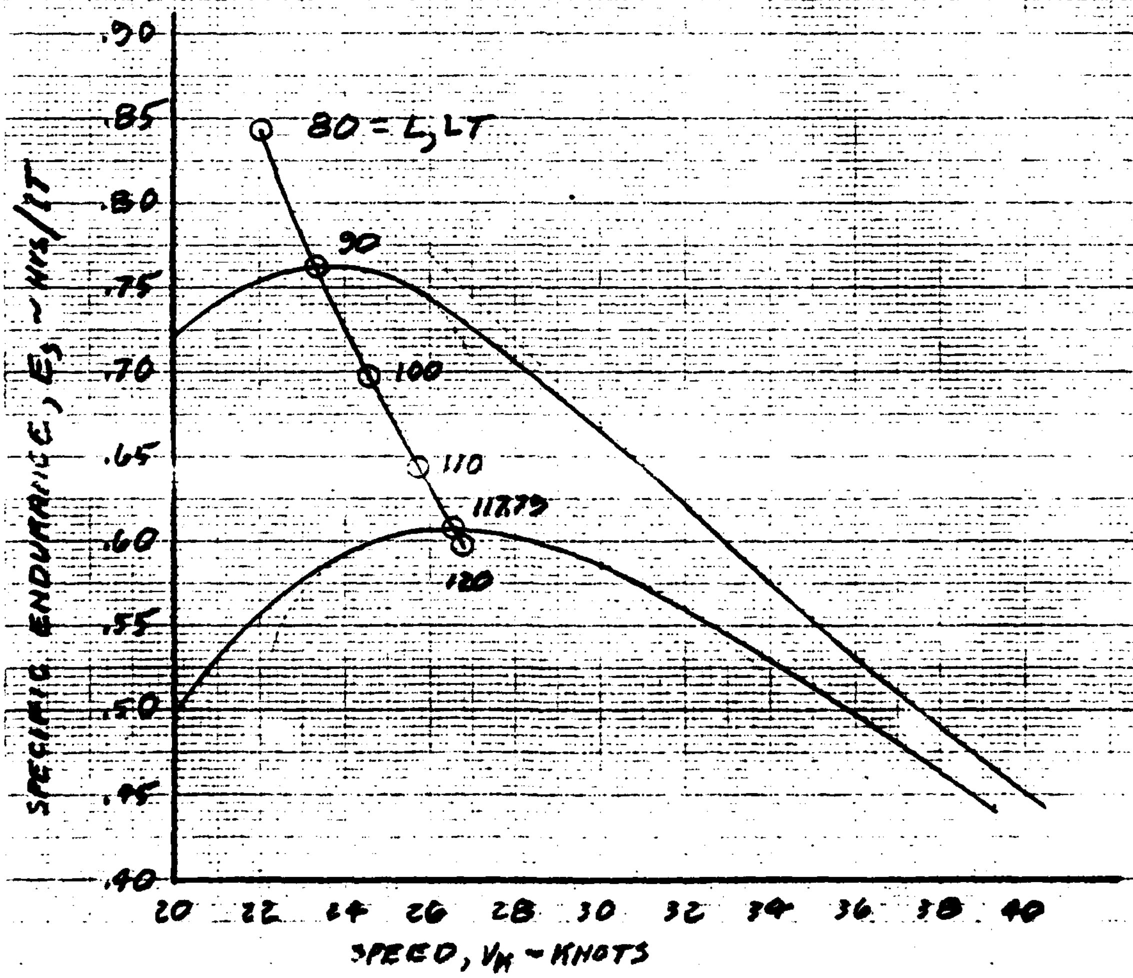


FIGURE 3-32

HRW 9/22/80

3.5.3 (Cont'd) Equation 3.5-4 is shown on Figure 3-33 as a function of dynamic lift for the drag polar of Figure 3-20 and for the rated continuous and maximum powers.

M169 TAKE OFF MARGIN

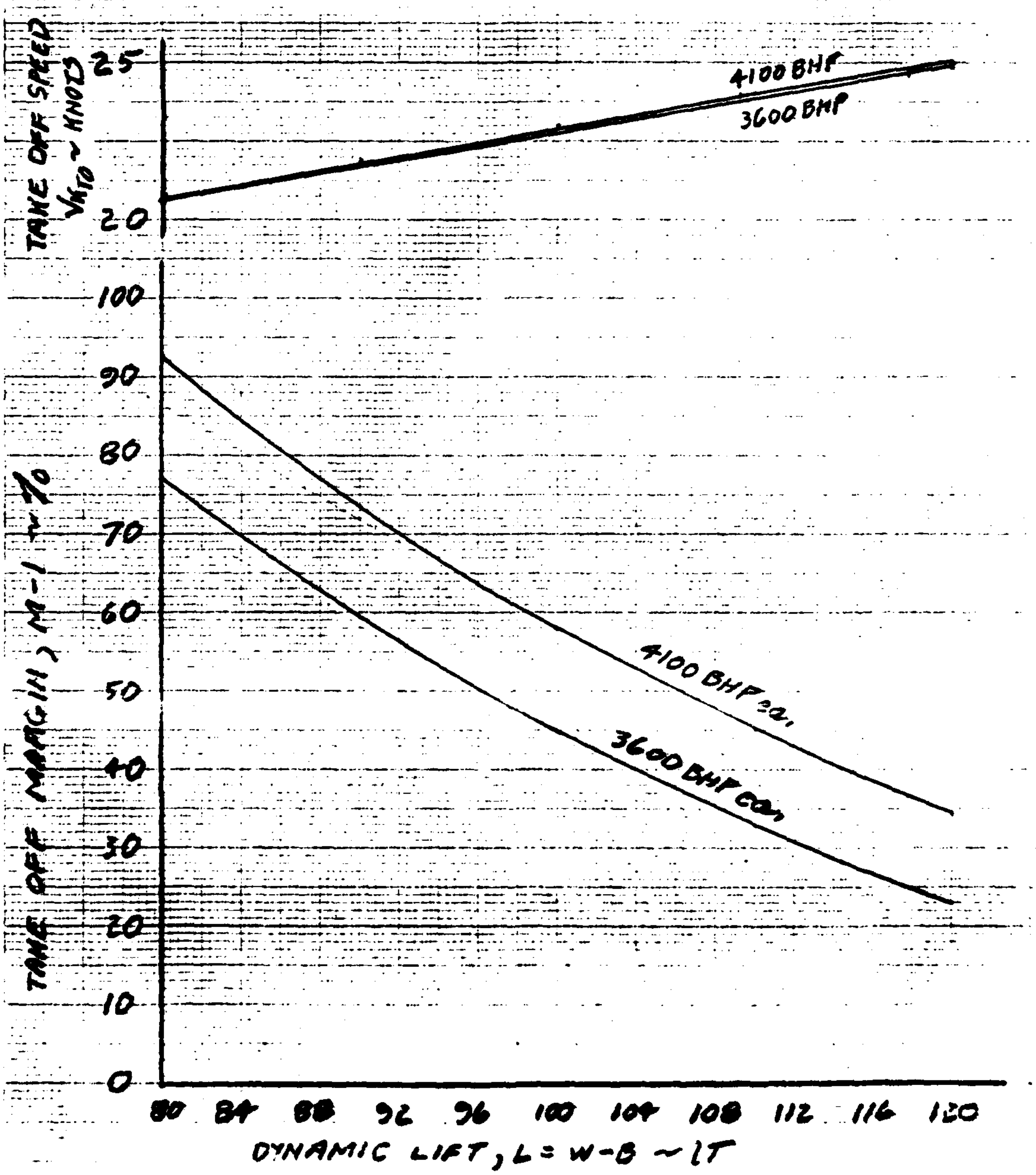


FIGURE 3-33

HRW 9/22/80

3.6 Maneuverability - Accountability for the effect of the tank upon the PCH turning characteristics required the derivation of a set of generalized (partially coordinated) turn equations. That derivation and a discussion of the general implications of the equations will be presented in Reference 19; only the application of the equations to the PCH and M169 is presented here. No speed equation is employed.

The craft axis system is employed with the following definition for positive values:

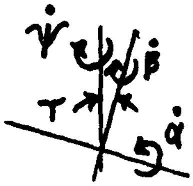
Lift, L - up
Side Force, Y - to starboard
Pitch, α - bow up
Sideslip Angle, β - bow to starboard
Roll, τ - starboard foil down
Pitching Moment, C_M - bow up
Yawing Moment, C_n - bow to starboard
Roll Moment, C_l - starboard foil up
Rudder Angle, δ_R - T.E. to port
Lift Flap Angle, δ , - T. E. down
Aileron Angle, δ' - starboard T.E. down

The turning (yaw) rate, $\dot{\psi}$, is given by:

$$\dot{\psi} = \frac{V}{R} = \frac{V}{\ell}\frac{\ell}{R} \qquad (3.6\text{-}1)$$

and is related to the pitch and sideslip rates by:

$$\begin{aligned} \dot{\alpha} &= \dot{\psi}\sin\tau = \frac{V}{\ell}\sin\tau\frac{\ell}{R} \\ \dot{\beta} &= \dot{\psi}\cos\tau = \frac{V}{\ell}\cos\tau\frac{\ell}{R} \end{aligned} \qquad (3.6\text{-}2)$$



3.6 (Cont'd) In the craft axis system the craft hydrodynamic loads in the steady state turn are:

$$\text{Weight, } C_L = \frac{W-B}{qS}\cos\gamma + \frac{W}{gqS}\frac{V^2}{R}\sin\gamma$$

$$\text{Side Force, } C_y = \frac{W}{gqS}\frac{V^2}{R}\cos\gamma - \frac{W-B}{qS}\sin\gamma \qquad (3.6\text{-}3)$$

where:

$$\frac{W-B}{qS} = \frac{117.79 \times 2240}{2.8387 V_K^2 \times 238.48} = \frac{389.75}{V_K^2}$$
$$= .24359 \text{ @ } 40 \text{ Kts.} \qquad (3.6\text{-}4)$$

$$\frac{W}{gqS}\frac{V^2}{R} = \frac{2W}{\rho g S l}\frac{l}{R} = \frac{2(120+63.42^*) \times 2240}{\rho g \times 238.48 \times 58.51}\frac{l}{R}$$

$$= (.60112 + .31769^*)\frac{l}{R}$$

where * indicates a tank increment. (3.6-5)

Surfaces displaced from the C.G. experience an induced angle of attack defined by:

$$\Delta\alpha = \pm\frac{l_i\dot{\alpha}}{V} = \pm\frac{l_i}{l}\frac{l}{V}\dot{\alpha} = \pm\frac{l_i}{l}\sin\gamma\frac{l}{R}$$

$$\Delta\beta = \pm\frac{l_i\dot{\beta}}{V} = \pm\frac{l_i}{l}\frac{l}{V}\dot{\beta} = \pm\frac{l_i}{l}\cos\gamma\frac{l}{R}$$

(3.6-6)

where the increment is positive for surfaces aft of the C.G.

3.6 The aft foil side force was estimated by:
(Cont'd)

$$C_{Y_{\beta_2}} = \frac{S_2}{S} C_{L\alpha_2} \sin^2 \Gamma$$

$$= \left(\frac{S_o}{S} \sin^2 \Gamma_o + \frac{S_i}{S} \sin^2 \Gamma_i\right) C_{L\alpha_2}$$

$$= \left(\frac{20.38 \times 4.75}{238.48} \sin^2 6^\circ + \frac{16 \times 4.75}{238.48} \sin^2 12^\circ\right) C_{L\alpha_2}$$

$$= (.4059 \times .01093 + .3187 \times .04323) C_{L\alpha_2}$$

$$= (.004436 + .01378) \times 3.4475$$

$$= .01821 \times 3.4475$$

$$= .06279 \qquad (3.6\text{-}7)$$

The strut side force slopes were estimated by:

$$C_{Y_\beta} = \frac{2\pi A}{AE + 2.12 K_E}$$

where: $A = \frac{h}{c} \approx 1$

$$E = 1 + \frac{1}{A} = 2$$

$$K_E = \frac{1 + b/h}{1 + 2b/h}$$

b = foil span fwd

foil semi-span was employed aft

(3.6-8)

3.6 (Cont'd.) For the fwd. strut, the corresponding side force slope is:

$$K_E = \frac{1 + \frac{2.0}{3.68}}{1 + \frac{4.0}{3.68}} = .54212 \qquad (3.6\text{-}9A)$$

$$C'_{Y_{\beta_1}} = C'_{Y_{\beta_2}} = \frac{2\pi}{2 + 2.12 \times .54212} = 1.9951$$

The aft strut side force slope is ill-defined and approximately the same as that for the forward strut.

The tank strut side force slope is:

$$C'_{Y_{\beta_{TS}}} = \frac{2\pi \times .85}{2.1765 \times .85 + 2.12} = 1.3453 \qquad (3.6\text{-}9B)$$

$$\text{for } A = \frac{8.5}{10}$$

Equation 3.6-8 is a Hoerner equation which described the FLAGSTAFF model test results well, but the numerical coefficient of the denominator is empirical and the wetted strut side force slope should be measured. The use of the wetted side force slope is, itself, a significant limitation upon the estimated turn performance for any significant strut yaw angle.

3.6
(Cont'd.) Because of the dihedral angles of the PCH aft foil, the aileron has a rudder action given by:

(3.6-10)

$$C'_{Y_{\delta'}} = C_{L_{\delta'_o}} \sin \Gamma_o - C_{L_{\delta'_I}} \sin \Gamma_I$$

$$= (1.3824 \sin 6^\circ - 1.6493 \sin 12^\circ) \times .535 \times .825 = -.087573$$

$$C_{Y_{\delta'}} = \frac{S_2}{S} C'_{Y_{\delta'}} = -.7248 \times .087573 = -.063473$$

where $C_{L_{\delta'}}$ is from Equation 3.7.1-6 and has been reduced by the flap effectiveness and depth effect.

The aft "rudder" has the slope of the tank fin, taken from Equation (92) of Reference 17:

(3.6-11)

$$C_{Y_{\delta'_R}} = .28322$$

3.6
(Cont'd.) The tank buoyancy introduces a rolling moment described by:

$$C_{l_B} = - \frac{B_T\, y_T \sin\tau}{\frac{\rho}{2} V^2 S l} \qquad (3.\ 12A)$$

$$= - \frac{65.63 \times 2240 \times 15.48 \sin\tau}{2.8387\, V_K^2 \times 238.48 \times 58.51}$$

$$= - \frac{57.45}{V_K^2} \sin\tau$$

No foil and strut buoyancy rolling moments are included here.

The tank buoyancy also introduces a pitching moment described by:

$$C_{m_B} = \frac{B_T\, x_T}{\frac{\rho}{2} V^2 S l} \qquad (3.6\text{-}12B)$$

$$= \frac{65.63 \times 2240 \times 4.9}{2.8387\, V_K^2 \times 238.48 \times 58.51}$$

$$= \frac{18.186}{V_K^2}$$

3.6 (Cont'd.) Yaw of the outboard foil panels has the effect of a positive aileron displacement:

$$C_{l_o} = \frac{C_{l_\delta}'}{.535} \delta_o' = \frac{.09324}{.535} \beta_2 \sin 6^\circ \qquad (3.6\text{-}13)$$

$$= .17428 \times .10453\ \beta_2$$

$$= .018217$$

Yaw of the inboard aft foil panels has the effect of a negative aileron displacement:

$$C_{l_I} = -\frac{b_i's}{l} \frac{S_2}{S} \frac{C_{L_i}'}{\delta_i} \delta_i \qquad (3.6\text{-}14)$$

$$= -\frac{8}{58.51} \times .7248 \times 2.1029 \times .825\ \beta_2 \sin 12^\circ$$

$$= -.035746\ \beta_2$$

Then the total rolling moment produced by yaw of the aft foil is:

$$C_{l_F} = C_{l_o} + C_{l_I} = (.018217 - .035746)\beta_2 \qquad (3.6\text{-}15)$$

$$= -.017529\ \beta_2$$

$$= -.017529\left(\beta + \frac{l_2}{D} \cos\gamma \frac{l}{R}\right)$$

3.6

(Cont'd.) The five turning equations are summarized on Figures 3-34 through 3-38. Time does not permit exploration of the pitch and speed effects, and the equations are examined only for a pitch of one degree and a speed of 40 knots. For those conditions, the PCH equations become:

(3.6-16)

$$.47904\,\delta_1 + 1.3368\,\delta_2 = .36152 \sin\gamma \frac{l}{R} + .24359 \cos\gamma - .24814$$

$$.3103\,\delta_1 - .47089\,\delta_2 = .72498 \sin\gamma \frac{l}{R} + .91748$$

$$.45531\,\beta - .57158 \cos\gamma \frac{l}{R} - .063473\,\delta' = -.13089\,\delta_R - .24359 \sin\gamma$$

$$-.029543\,\beta - .095158 \cos\gamma \frac{l}{R} + .022358\,\delta' = -.084752\,\delta_R$$

$$.092808\,\beta - .004087 \cos\gamma \frac{l}{R} + .1586\,\delta' = -.036779\,\delta_R$$

The turn characteristics are established by the lateral equations; the pitch plane then provides the lift flap angles required.

The solutions for the lateral equations are:

(3.6-17)

$$\beta = .44841\,\delta_R - .32444 \sin\gamma$$

$$\cos\gamma \frac{l}{R} = .63916\,\delta_R + .14622 \sin\gamma$$

$$\delta' = -.47782\,\delta_R + .19362 \sin\gamma\,.$$

LIFT EQUATION

Fwd Foil, Equation 3.7.2-1: $C_{L_1}' = 3.5935\,\alpha_1 + 1.7407\,\delta_1 + .2122$

$\frac{S_1}{S} = .2752,\ \frac{\ell_1}{\ell} = .64775,\ \frac{\ell_1}{\ell}\frac{S_1}{S} = .17826$

$$C_{L_1} = \frac{S_1}{S} C_{L_1}' = 3.5935\frac{S_1}{S} - 3.5935\frac{\ell_1}{\ell}\frac{S_1}{S}\sin\gamma\frac{\ell}{R} + 1.7407\frac{S_1}{S}\delta_1 + .2122\frac{S_1}{S}$$
$$= .98893\,\alpha - .64058\sin\gamma\frac{\ell}{R} + .47904\,\delta_1 + .058397$$

Aft Foil, Equation 3.7.1-10: $C_{L_2}' = 3.4475\,\alpha_2 + 1.8444\,\delta_2 + .1778$

$\frac{S_2}{S} = .7248,\ \frac{\ell_2}{\ell} = .35225,\ \frac{\ell_2}{\ell}\frac{S_2}{S} = .25531$

$$C_{L_2} = \frac{S_2}{S} C_{L_2}' = 3.4475\frac{S_2}{S}\alpha + 3.4475\frac{\ell_2}{\ell}\frac{S_2}{S}\sin\gamma\frac{\ell}{R} + 1.8444\frac{S_2}{S}\delta_2 + .1778\frac{S_2}{S}$$
$$= 2.4987\,\alpha + .88018\sin\gamma\frac{\ell}{R} + 1.3368\,\delta_2 + .12887$$

Tank, Reference 20:

$$C_{L_T} = .45655\,\alpha - .011705\,\dot{\alpha} = .45655\,\alpha - .011705\sin\gamma\frac{\ell}{R}$$

$$C_{L_1} + C_{L_2} + C_{L_T} = C_L\cos\gamma + C_y\sin\gamma$$

$$(3.4876 + .45655^*)\alpha + (.23960 - .011705^*)\sin\gamma\frac{\ell}{R} + .47904\,\delta_1$$
$$+ 1.3368\,\delta_2 + .18727 = \frac{389.75}{V_K^2}\cos\gamma + (.60112 + .31769^*)\sin\gamma\frac{\ell}{R}$$

$$C_{L_\alpha}\alpha - C_{m_{\dot{\alpha}}}\sin\gamma\frac{\ell}{R} + C_{L_{\delta_1}}\delta_1 + C_{L_{\delta_2}}\delta_2 + C_{L_0} = C_L\cos\gamma + C_y\sin\gamma$$

$$.47904\,\delta_1 + 1.3368\,\delta_2 = \frac{389.75}{V_K^2}\cos\gamma - (3.4876 + .45655^*)\,\alpha$$
$$- .18727 + (.36152 + .32940^*)\sin\gamma\frac{\ell}{R}$$

* INDICATES INCREMENT FOR TANK.

Figure 3-34

PITCH MOMENT EQUATION

Fwd. Foil: $C_{m_1} = \frac{l_1}{l} C_{L_1}$

$$= .64058\alpha - .41494 \sin\tau \frac{l}{R} + .31030\delta_1 + .037827$$

Aft Foil: $C_{m_2} = -\frac{l_2}{l} C_{L_2}$

$$= -.88017\alpha - .31004 \sin\tau \frac{l}{R} - .23695\delta_2 - .045394$$

Tank: $C_{m_T} = .011705\alpha - .25854 \sin\tau \frac{l}{R}$

$C_{m_B} = \frac{18.186}{V_K^2}$

$$C_{m_1} + C_{m_2} + C_{m_T} + C_{m_B} = 0$$

$$(-.2396 + .011705^*)\alpha - (.72498 + .25854^*)\sin\tau \frac{l}{R} + \frac{18.186}{V_K^2}^* + .3103\delta_1 - .23695\delta_2 - .007567 = 0$$

$$C_{m_\alpha}\alpha + C'_{m_\alpha}\sin\tau \frac{l}{R} + C_{m_B}^* + C_{m_{\delta_1}}\delta_1 + C_{m_{\delta_2}}\delta_2 + C_{m_0} = 0$$

$$.3103\delta_1 - .47089\delta_2 = (.2396 - .011705^*)\alpha + .007567 - \frac{18.186}{V_K^2}^* + (.72498 + .25854^*)\sin\tau \frac{l}{R}$$

* INDICATES INCREMENT FOR TANK

Figure 3-35

SIDE FORCE EQUATION

Fwd. Strut: $C_{Y_{S_1}} = \frac{S_{S_1}}{S} C_{Y_{\beta_{S_1}}} \beta_1 = .06558 \times 1.9951 \left(\beta - \frac{\ell_1}{\ell} \cos\gamma \frac{\ell}{R}\right)$

$= .13084\beta - .13084 \times .64775 \cos\gamma \frac{\ell}{R}$

$= .13084\beta - .084751 \cos\gamma \frac{\ell}{R}$

Aft Strut: $C_{Y_{S_2}} = \frac{S_{S_2}}{S} C_{Y_{\beta_{S_2}}} \beta_2 = .1316 \times 1.9951 \left(\beta + \frac{\ell_2}{\ell} \cos\gamma \frac{\ell}{R}\right)$

$= .26168\beta + .26168 \times .35225 \cos\gamma \frac{\ell}{R}$

$= .26168\beta + .092176 \cos\gamma \frac{\ell}{R}$

Aft Foil: $C_{Y_2} = C_{Y_{\beta_2}} \beta_2 = .06279 \left(\beta + \frac{\ell_2}{\ell} \cos\gamma \frac{\ell}{R}\right)$

$= .06279\beta + .06279 \times .35225 \cos\gamma \frac{\ell}{R}$

$= .06279\beta + .022118 \cos\gamma \frac{\ell}{R}$

Tank: $C_{Y_T} = .45655\beta - .011705 \cos\gamma \frac{\ell}{R}$

Tank Strut: $C_{Y_{TS}} = \frac{S_{TS}}{S} C'_{Y_{\beta_{TS}}} = \frac{85}{238.48} \times 1.3453 \left(\beta - .12647 \cos\gamma \frac{\ell}{R}\right) = .4795\beta - .060642 \cos\gamma \frac{\ell}{R}$

$$C_{Y_{S_1}} + C_{Y_{S_2}} + C_{Y_F} + C_{Y_T} + C_{Y_{TS}} + C_{Y_{\delta'}} \delta' + C_{Y_{\delta_R}} \delta_R + C_{Y_{\delta'_R}} \delta'_R = C_Y \cos\gamma - C_L \sin\gamma$$

$$(.45531 + .93605^*)\beta + (.029543 - .072347^*)\cos\gamma \frac{\ell}{R} - .063473\,\delta'$$
$$+ .13084\,\delta_R + .28322\,\delta'_R = (.60112 + .31769^*)\cos\gamma \frac{\ell}{R} - \frac{389.75}{V_K^2}\sin\gamma$$

$$C_{Y_\beta}\beta - C_{n_\beta}\cos\gamma \frac{\ell}{R} + C_{Y_{\delta'}}\delta' + C_{Y_{\delta_R}}\delta_R + C_{Y_{\delta'_R}}\delta'_R = C_Y \cos\gamma - C_L \sin\gamma$$

$$(.45531 + .93605^*)\beta - (.57158 + .39004^*)\cos\gamma \frac{\ell}{R} - .063473\,\delta'$$
$$= -.13084\,\delta_R - .28322\,\delta'_R - \frac{389.75}{V_K^2}\sin\gamma$$

* INDICATES INCREMENT FOR TANK

Figure 3-36

YAWING MOMENT EQUATION

$$\frac{l_1}{l}C_{Y_{S_1}} - \frac{l_2}{l}C_{Y_{S_2}} - \frac{l_2}{l}C_{Y_F} + C_{n_T} - \frac{l_2}{l}C_{Y_{S'}}\delta' + \frac{l_1}{l}C_{Y_{S_R}}\delta_R - \frac{l_{S_R'}}{l}C_{Y_{S_R'}}\delta_R' + \frac{l_{TS}}{l}C_{Y_{TS}} = 0$$

$$\frac{l_1}{l} = .64775,\quad \frac{l_2}{l} = .35225,\quad \frac{l_{S_R'}}{l} = \frac{40.5}{58.51} = .69219$$

$$C_{n_{S_1}} = .084751\,\beta - .054898\cos\tau\frac{l}{R}$$
$$C_{n_{S_2}} = -.092176\,\beta - .032469\cos\tau\frac{l}{R}$$
$$C_{n_F} = -.022118\,\beta - .0077910\cos\tau\frac{l}{R}$$
$$C_{n_T} = .011705\,\beta - .25854\cos\tau\frac{l}{R}$$
$$C_{n_{TS}} = .060642\,\beta - .0076694\cos\tau\frac{l}{R}$$

$$(-.029543 + .072347^*)\beta - (.095158 + .26621^*)\cos\tau\frac{l}{R} + .022358\,\delta'$$
$$= -.084752\,\delta_R + .19604\,\delta_R'$$

$$C_{n_\beta}\beta + C_{n_\beta}'\cos\tau\frac{l}{R} + C_{n_{\delta'}}\delta' = -C_{n_{\delta_R}}\delta_R - C_{n_{\delta_R'}}\delta_R'$$

* INDICATES INCREMENT FOR TANK

Figure 3-37

ROLLING MOMENT EQUATION

$$\frac{y_{s_1}}{l} C_{Y_{s_1}} + \frac{y_{s_2}}{l} C_{Y_{s_2}} + C_{l_F} + C_{l_T} + C_{l_{\delta'}} \delta' + \frac{y_{s_1}}{l} C_{Y_{\delta_R}} \delta_R + \frac{y_T}{l} C'_{Y_{\delta_R}} \delta'_R + C_{l_B} + \frac{y_{TS}}{l} C_{Y_{TS}} = 0$$

where: $y_{s_1}/l = y_{s_2}/l = .2811 - .1246^*$

$y_T/l = .26457$

C_{l_F} is from Equation 3.6-15

C_{l_T} is from Reference 20

$C_{l_{\delta'}}$ is from Equation 3.7.1-11

C_{l_B} is from Equation 3.6-12

$$C_{l_{s_1}} = .020476\beta - .013263 \cos\gamma \frac{l}{R}$$
$$C_{l_{s_2}} = .040953\beta + .014425 \cos\gamma \frac{l}{R}$$
$$C_{l_F} = -.017529\beta - .0061746 \cos\gamma \frac{l}{R}$$
$$C_{l_T} = .12079\beta - .0030968 \cos\gamma \frac{l}{R}$$
$$C_{l_{TS}} = .092196\beta - .01166 \cos\gamma \frac{l}{R}$$

$$(.092808 + .16408^*)\beta - (.004087 + .015683^*) \cos\gamma \frac{l}{R} + .1586\,\delta' + (.036779 - .016303^*)\delta_R + .074932\,\delta'_R - \frac{57.45^*}{V_R^2} \sin\gamma = 0$$

$$C_{l_\beta}\beta + C'_{l_\beta} \cos\gamma \frac{l}{R} + C_{l_{\delta'}}\delta' + C_{l_{\delta_R}}\delta_R + C_{l_{\delta'_R}}\delta'_R + C_{l_B} = 0$$

$$(.092808 + .16408^*)\beta - (.004087 + .015683^*) \cos\gamma \frac{l}{R} + .1586\,\delta' = -(.036779 - .016303^*)\delta_R - .074932\,\delta'_R + \frac{57.45^*}{V_R^2} \sin\gamma$$

* INDICATES INCREMENT FOR TANK

Figure 3-38

3.6 (Cont'd.) The fwd. strut sideslip angle and the rudder angle required for a zero sideslip angle are then given by:

(3.6-18)

$$\beta_1 = \beta - \frac{l_1}{l}\cos\gamma\frac{l}{R} + \delta_R \qquad \text{where } \frac{l_1}{l} = .64775$$

$$= 1.0344\,\delta_R - .41915\sin\gamma = 0$$

$$\delta_R = .40521\sin\gamma$$

For the aft strut

(3.6-19)

$$\beta_2 = \beta + \frac{l_2}{l}\cos\gamma\frac{l}{R} \qquad \text{where } \frac{l_2}{l} = .35225$$

$$= .67355\,\delta_R - .27253\sin\gamma = 0$$

$$\delta_R = .40521\sin\gamma$$

and directly from Equation 3.6-17 the rudder angle required to zero the aileron is:

(3.6-20)

$$\delta_R = .19362\sin\gamma/.47782 = .40521\sin\gamma$$

Equations 3.6-18, -19, and -20 comprise the definition for the coordinated turn and provide the rudder angle required to coordinate the turn for any given roll angle. Equation 3.6-17 describes the angles required for any degree of partial coordination.

3.6 (Cont'd.) For the coordinated turn rudder angle, the ℓ/R of Equation 3.6-17 becomes:

(3.6-20A)

$$\cos\gamma \frac{\ell}{R} = .63916 \times .40521 \sin\gamma + .14622 \sin\gamma$$
$$= .40521 \sin\gamma$$
$$\frac{\ell}{R} = .40521 \tan\gamma$$

The classic solution for the coordinated turn notes that the roll angle is defined by:

$$\tan\gamma = \frac{Wa}{L} = \frac{WV^2}{gRL} = \frac{WV^2}{Lg\ell}\frac{\ell}{R} \qquad (3.6\text{-}20B)$$

$$\frac{\ell}{R} = \frac{L}{W}\frac{g\ell}{V^2}\tan\gamma$$

$$= \frac{117.79}{120} \times \frac{58.51\,g}{(67.556)^2}\tan\gamma \quad (\text{For } 40 \text{ Knots})$$

$$= .40521 \tan\gamma$$

Since the craft is rotating about the fixed strut, the aft strut, the steerable strut must be set to:

(3.6-20C)

$$\delta_R = \frac{\ell}{R}\cos\gamma = .40521 \sin\gamma$$

3.6 (Cont'd.) Note that Equations 3.6-17,-18, and -19 also contain the case for zero coordination, the flat turn, where Equation 3.6-18 limits the rudder angle to that for strut closure.

The solutions for the pitch equations of Equation 3.6-16 are:

$$\begin{aligned} \delta_1 &= .17911 \cos\gamma - .15794 + 1.7792 \sin\gamma \frac{\ell}{R} \\ \delta_2 &= .11803 \cos\gamma - .12902 - .36715 \sin\gamma \frac{\ell}{R} \end{aligned} \tag{3.6-21}$$

which may be written:

$$\begin{aligned} \delta_1 &= -.15734 + .17911 \cos\gamma + 1.7792 \tan\gamma \cos\gamma \frac{\ell}{R} \\ \delta_2 &= -.12902 + .11803 \cos\gamma - .36715 \tan\gamma \cos\gamma \frac{\ell}{R} \end{aligned} \tag{3.6-22}$$

which provides the trim lift flap angles for any roll angle at any turn radius, including the cases for straight flight in rolled attitude, flat, or coordinated turns.

For the coordinated turn of Equation 3.6-18, Equation 3.6-22 becomes:

$$\begin{aligned} \delta_1 &= -.15794 + .17911 \cos\gamma + .72095 \sin\gamma \tan\gamma \\ \delta_2 &= -.12902 + .11803 \cos\gamma - .14878 \sin\gamma \tan\gamma \end{aligned} \tag{3.6-23}$$

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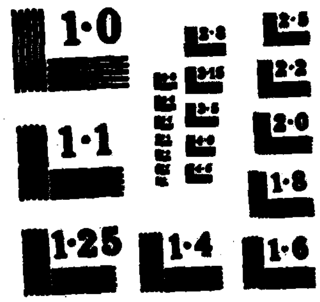
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3.6 (Cont'd.) Taking the case of a 15 ° roll angle for illustration, the turn performance is:

$$\frac{l}{R} = .40521 \tan 15^\circ = .10858 \tag{3.6-24}$$
$$R = 9.2102\, l = 9.2102 \times 58.51 = 538.89 \text{ ft.}$$
$$\dot{\gamma} = 1.654 \frac{l}{R} V_R = 1.654 \times .10858 \times 40 = 7.1836 \text{ deg./sec.}$$

Summarizing the angles required and evaluation for a 15° roll angle:

$$\delta_R \doteq .40521 \sin \gamma = .10488 = 6.0094 \text{ deg.}$$
$$\beta = .44891\, \delta_R - .32444 \sin \gamma = -.036942 = -2.1168 \text{ deg.}$$
$$\beta_1 = 0$$
$$\beta_2 = 0$$
$$\delta' = 0$$
$$\delta_1 = .72095 \sin \gamma \tan \gamma + .17911 \cos \gamma - .15794 = .065065 = 3.7282^\circ$$
$$\delta_2 = -.14878 \sin \gamma \tan \gamma + .11803 \cos \gamma - .12902 = -.025330 = -1.4514^\circ$$

(3.6-25)

Comparison with the limiting angles of Figure 3-39 indicates that the forward flap angle requirement will be increased by hinge line cavitation.

NOMINAL ANGULAR CAVITATION LIMITS

40 KNOTS

$|\beta_1| \leq$ 5° = .08726, FLAGSTAFF model ventilation limit

$|\beta_2| \leq$ 5° = .08726, FLAGSTAFF model ventelation limit

$-.04363 = -2\frac{1}{2}° \leq \delta_2 \leq 3\frac{1}{2}° = .061082$, Figure 3-48

Lower limit is effective boundary. Upper limit is incipient hinge boundary.

$|\zeta'| \leq$ 5° = .08726, Figure 3-49.

Conservatively set at incipient hinge boundary, port or starboard.

$-.04363 = -2\frac{1}{2}° \leq \zeta_1 \leq 2\frac{1}{2}° = .04363$, Figure 3-50.

Lower limit is intersection of 1.25% and 60% chord station boundaries.

Upper limit is measured effective boundary for hinge line.

Figure 3-39

3.6 (Cont'd.) For the M169 with fixed tank fin and at 40 knots with 1° of pitch the turn equations become:

(3.6-26)

$$.47904\,\delta_1 + 1.3368\,\delta_2 = .29359\cos\gamma - .2561 + .69092\sin\gamma\,\frac{\ell}{R}$$
$$.3103\,\delta_1 - .47089\,\delta_2 = .000178 + .98352\sin\gamma\,\frac{\ell}{R}$$

$$1.3914\,\beta - .36162\cos\gamma\,\frac{\ell}{R} - .063473\,\delta' = -.13084\,\delta_R - .29359\sin\gamma$$
$$.042804\,\beta - .36137\cos\gamma\,\frac{\ell}{R} + .022358\,\delta' = -.084752\,\delta_R$$
$$.25683\,\beta - .01977\cos\gamma\,\frac{\ell}{R} + .1586\,\delta' = -.020476\,\delta_R + .035906\sin\gamma$$

having the solutions:

(3.6-27)

$$\delta_1 = -.18794 + .17911\cos\gamma + 2.5611\tan\gamma\cos\gamma\,\frac{\ell}{R}$$
$$\delta_2 = -.12423 + .11803\cos\gamma - .40094\tan\gamma\cos\gamma\,\frac{\ell}{R}$$

$$\beta = .055752\,\delta_R - .14599\sin\gamma$$
$$\cos\gamma\,\frac{\ell}{R} = .22953\,\delta_R + .011433\sin\gamma$$
$$\delta' = -.19082\,\delta_R + .46428\sin\gamma$$

3.6 (Cont'd.) For this case, the coordinated turn as defined at the fwd. and aft struts and aileron requires a rudder angle of:

(3.6-28)

$$\beta_1 = \beta - \frac{l_1}{l}\cos\gamma\frac{l}{R} + \delta_R \qquad \text{where } \frac{l_1}{l} = .64775$$
$$= .3072\,\delta_R - .1534\sin\gamma = 0$$
$$\delta_R = .16909\sin\gamma$$

(3.6-29)

$$\beta_2 = \beta + \frac{l_2}{l}\cos\gamma\frac{l}{R} \qquad \text{where } \frac{l_2}{l} = .35225$$
$$= .13653\,\delta_R .14196\sin\gamma = 0$$
$$\delta_R = 1.0398\sin\gamma$$

(3.6-30)

$$\delta' = -.19082 + .46428\sin\gamma = 0$$
$$\delta_R = 2.433\sin\gamma$$

3.6 (Cont'd.) The PCH has hydrodynamic loads at two locations, one of which is steerable. The M169 has hydrodynamic loads at three additional longitudinal positions; tank forebody, afterbody, and fin; and can only provide a zero yaw for one position. In fact, the ℓ/R result indicates that it is desirable to make the rudder angle as large as possible. The limiting angle for this case is the fwd. strut yaw angle and setting that angle equal to 5° =

(3.6-31)

$$\beta_1 = .9072\,\delta_R - .1534 \sin \gamma = .08726$$

$$\delta_R = .096186 + .16909 \sin \gamma$$

The turn radius then becomes:

(3.6-32)

$$\cos \gamma \frac{\ell}{R} = .022058 + .05021 \sin \gamma$$

$$\frac{\ell}{R} = \frac{.022058}{\cos \gamma} + .05021 \tan \gamma$$

$$= .03629 \qquad \text{for } \gamma = 15^{\circ}$$

$$R = 27.556\,\ell = 27.556 \times 58.51 = 1612.3 \text{ ft,}$$

$$\dot{\gamma} = 1.654 \frac{\ell}{R} V_K = 1.654 \times .03629 \times 40 = 2.4009 \text{ deg/sec,}$$

3.6 (Cont'd.) The coordinated turn for this case would provide:

$$\frac{l}{R} = \frac{L l g}{W V^2} = \frac{117.79 \times 58.51 g}{183.42 (67.556)^2} \tan\gamma = .26511 \tan\gamma \quad (3.6\text{-}33)$$

$$= .071036 \text{ for } \gamma = 15^\circ$$

$$R = 14.077\, l = 823.67 \text{ ft.}$$
$$\dot{\psi}^\circ = 4.6997 \text{ deg./sec.}$$

The angles corresponding to this case are:

$$\delta_R = .096186 + .16909 \sin\gamma = .13995 = 8.0191^\circ \quad (3.6\text{-}34)$$
$$\beta = .055752\,\delta_R - .14599 \sin\gamma = -.029982 = -1.7179^\circ$$
$$\beta_1 = .08726 + 0 = .08726 = 5^\circ$$
$$\beta_2 = .013132 - .11887 \sin\gamma = -.017634 = -1.0104^\circ$$
$$\delta_1 = -.18794 + .17911 \cos\gamma + .056493 \tan\gamma + .12859 \sin\gamma \tan\gamma$$
$$= .009122 = .5227^\circ$$
$$\delta_2 = -.12423 + .11803 \cos\gamma - .0088439 \tan\gamma - .020131 \sin\gamma \tan\gamma$$
$$= -.013988 = -.8015^\circ$$
$$\delta' = -.19082\,\delta_R + .46428 \sin\gamma = .093459 = 5.3552^\circ$$

Except for the fwd. strut sideslip angle which indicates a substantial strut load, these angles present no problems.

3.6 (Cont'd.) If the tank fin is made moveable to assist the existing rudder, Equation (92) of Reference 20 provides the following rudder characteristics:

$$C_{Y\delta_R}' = .28322 \tag{3.6-35}$$

$$C_{n\delta_R}' = -\frac{l_{fin}}{l} C_{Y\delta_R}' = -\frac{40.5}{58.51} \times .28322 = -.19604$$

$$C_{l\delta_R}' = \frac{Y_{fin}}{l} C_{Y\delta_R}' = \frac{15.48}{58.51} \times .28322 = .074932$$

These slopes appear on the right side of the lateral equations of Equation 3.6-26 with reversed signs and the solutions of Equation 3.6-27 become:

(3.6-36)

$$\delta_1 = -.18794 + .17911 \cos\gamma + 2.5611 \tan\gamma \cos\gamma \frac{l}{R}$$

$$\delta_2 = -.12423 + .11803 \cos\gamma - .40094 \tan\gamma \cos\gamma \frac{l}{R}$$

$$\beta = .055752\,\delta_R - .51119\,\delta_R' - .14599 \sin\gamma$$

$$\cos\gamma \frac{l}{R} = .22933\,\delta_R - .52664\,\delta_R' + .011433 \sin\gamma$$

$$\delta' = -.19082\,\delta_R + 1.23478\,\delta_R' + .46428 \sin\gamma$$

3.6 (Cont'd.) Now two of the conditions for the fully coordinated turn can be satisfied. Presumably, it is desirable to eliminate the strut load for structural reasons though, in fact, aileron angles still load the aft struts and the autopilot provides a coordinated turn at only one speed without speed adaptation.

Setting the two strut sideslip angles at zero:

(3.6-37)

$$\beta_1 = \beta - \frac{\ell_1}{\ell}\cos\gamma\,\frac{\ell}{R} + \delta_A \qquad \text{where } \frac{\ell_1}{\ell} = .64775$$

$$= .9072\,\delta_A - .17006\,\delta_A' - .1534\sin\gamma = 0$$

$$.9072\,\delta_A - .17006\,\delta_A' = .1534\sin\gamma$$

(3.6-38)

$$\beta_2 = \beta + \frac{\ell_2}{\ell}\cos\gamma\,\frac{\ell}{R} \qquad \text{where } \frac{\ell_2}{\ell} = .35225$$

$$= .13653\,\delta_A - .69678\,\delta_A' - .14196\sin\gamma$$

$$.13653\,\delta_A - .69678\,\delta_A' = .14196\sin\gamma$$

having the solutions:

$$\delta_A = .13589\sin\gamma \qquad (3.6\text{-}39)$$

$$\delta_A' = -.17713\sin\gamma = -1.3035\,\delta_A$$

3.6 (Cont'd) Now the turn performance becomes:

(3.6-40)

$$\cos\gamma \frac{l}{R} = .22933\,\delta_R - .15264\,\delta_R' + .011433 \sin\gamma$$

$$= .13588 \sin\gamma$$

$$\frac{l}{R} = .13588 \tan\gamma \quad \text{cf. } .26511 \tan\gamma \text{ for co-turn}$$

Comparison with Equation 3.6-33 shows that a heavy penalty is still being paid for the tank.

For a 15° roll angle the turn characteristics are:

$$\delta_R = .035171 = 2.0153^\circ \qquad (3.6\text{-}41)$$

$$\delta_R' = -.045845 = -2.6269^\circ$$

$$\frac{l}{R} = .036409, \quad R = 27.466\,l = 1607 \text{ ft.}$$

$$\dot{\psi} = 1.654 \frac{l}{R} V_R = 2.4088 \text{ deg./sec.}$$

$$\beta_1 = 0$$

$$\beta_2 = 0$$

$$\delta' = .056843 = 3.2571^\circ$$

$$\beta = -.012389 = -.70987^\circ$$

$$\delta_1 = .0092011 = .52722^\circ$$

$$\delta_2 = -.014 = -.8022^\circ$$

Equations 3.6-25, 3.6-34, and 3.6-41 are compared on Figure 3-40 which includes an illustration of the turn performance benefit available by loading the struts.

TURN CHARACTERISTICS

40 KNOTS $\alpha = 1°$ $\gamma = 15°$

	PCH (1)	M169 CONTROLLED FIN (2)	M169 CONTROLLED FIN (3)	M169 FIXED FIN (3)	LIMIT ANGLES DEG.
Rudder Angle, δ_R, deg.	6.0	2.0	6.3	8.0	
Fin Angle, δ_R', deg.	-	-2.6	-9	-	
Turn R, Foil Base Lengths	9.2	27.5	8.7	27.5	
Turn Radius, $\dot{R}$, ft.	539	1610	511	1610	
Turn Rate, $\dot{\psi}$, deg./sec.	7.2	2.4	7.6	2.4	
Craft Sideslip Angle, β, deg.	-2.1	-.7	2.8	-1.7	
Fwd. Strut Sideslip, β_1, deg.	0	0	5	5	± 5
Aft Strut Sideslip, β_2, deg.	0	0	5	-1	± 5
Aileron Angle, δ', deg.	0	3⅝	-5.3	5.3	± 5
Fwd. Flap Angle, δ_1, deg.	3.7(4)	½	3.5(4)	½	± 2½
Aft Flap Angle, δ_2, deg.	-1.5	-.8	-1.3	-.8	+3½, -2½

NOTES:
(1) Coordinated turn
(2) Zero strut yaw
(3) Best available turn for angular limitations
(4) Anticipate about 2° increase for hinge line cavitation

FIGURE 3-40

3.6 (Cont'd.) Left general in craft speed the M169 equations for one degree of pitch become:

(3.6-42)

$$.47904\delta_1 + 1.33688\delta_2 = \frac{389.75}{V_K^2}\cos\gamma - .2561 + .69092\sin\gamma\frac{\ell}{R}$$
$$.3103\,\delta_1 - .47089\delta_2 = .011544 - \frac{18.186}{V_K^2} + .98352\sin\gamma\frac{\ell}{R}$$

$$1.3918\beta - .96162\cos\gamma\frac{\ell}{R} - .063473\,\delta' = -.13084\delta_R - .28322\,\delta_R' - \frac{389.75}{V_K^2}\sin\gamma$$
$$.042804\beta - .36137\cos\gamma\frac{\ell}{R} + .022358\delta' = -.084752\delta_R + .19604\,\delta_R'$$
$$.25689\beta - .01977\cos\gamma\frac{\ell}{R} + .1586\,\delta' = -.020476\delta_R - .074932\,\delta_R' + \frac{57.45}{V_K^2}\sin\gamma$$

having the solutions:

(3.6-43)

$$\beta = .055752\,\delta_R - .51119\,\delta_R' - \frac{233.58}{V_K^2}\sin\gamma$$
$$\cos\gamma\frac{\ell}{R} = .22933\,\delta_R - .52664\,\delta_R' + \frac{18.293}{V_K^2}\sin\gamma$$
$$\delta' = -.19082\,\delta_R + 1.23488\,\delta_R' + \frac{742.85}{V_K^2}\sin\gamma$$

$$\delta_1 = -.16922 - \frac{37.963}{V_K^2} + \frac{286.58}{V_K^2}\cos\gamma + .25611\sin\gamma\frac{\ell}{R}$$
$$\delta_2 = -.13273 + \frac{13.606}{V_K^2} + \frac{188.85}{V_K^2}\cos\gamma - .40094\sin\gamma\frac{\ell}{R}$$

One important consequence of these solutions is the relationship:

(3.6-44)

$$\left.\begin{aligned}\delta_R &= \frac{217.41}{V_K^2}\sin\gamma\\ \delta_R' &= -\frac{283.42}{V_K^2}\sin\gamma = -1.3036\,\delta_R\end{aligned}\right\}\ \text{For } P_1 = P_2 = \ell$$

3.6 (Cont'd.) That is, the δ_F / δ_R' relationship is independent of speed.

Equation 3.6-43 also provides:

(3.6-45)

$$\delta' = \frac{351.4}{V_K^2} \sin \tau = 1.6163\, \delta_\eta \quad \text{for } \beta_1 = \beta_2 = 0$$

That is, a fixed ratio between the rudder and aileron angles insures this form of coordination.

Other consequences of Equation 3.6-43 are shown on Figures 3-41 thru 3-44. Figure 3-41 presents the bank angle required as a function of turn rate for three speeds. Turn rate is limited to 3 or 4 degrees/sec., depending upon craft speed, by aileron cavitation. Figure 3-42 presents turn radius as a function of turn rate. Figure 3-43 presents the rudder angle requirement as a function of turn rate. Figure 3-44 presents the craft sideslip angles and fin angles of attack. The negative craft sideslip angles are characteristic of fixed aft strut craft.

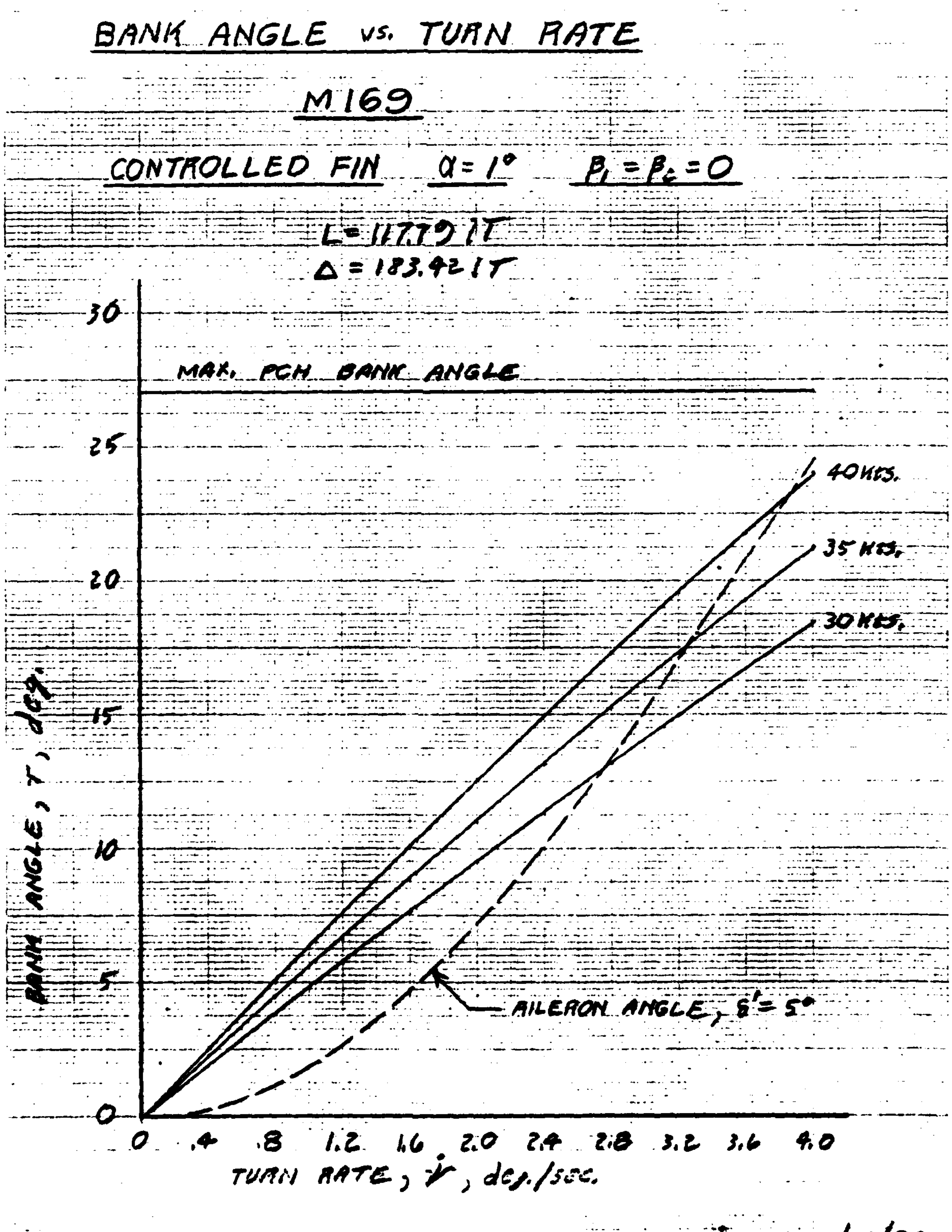
BANK ANGLE vs. TURN RATE
M169
CONTROLLED FIN α = 1° β1 = β2 = 0
L = 117.79 IT
Δ = 183.42 IT
MAX. PCH BANK ANGLE
40 KTS.
35 KTS.
30 KTS.
AILERON ANGLE, δ' = 5°
BANK ANGLE, T, deg.
TURN RATE, ψ̇, deg./sec.
0
5
10
15
20
25
30
0
.4
.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
MRW 10/29/80

FIGURE 3-41

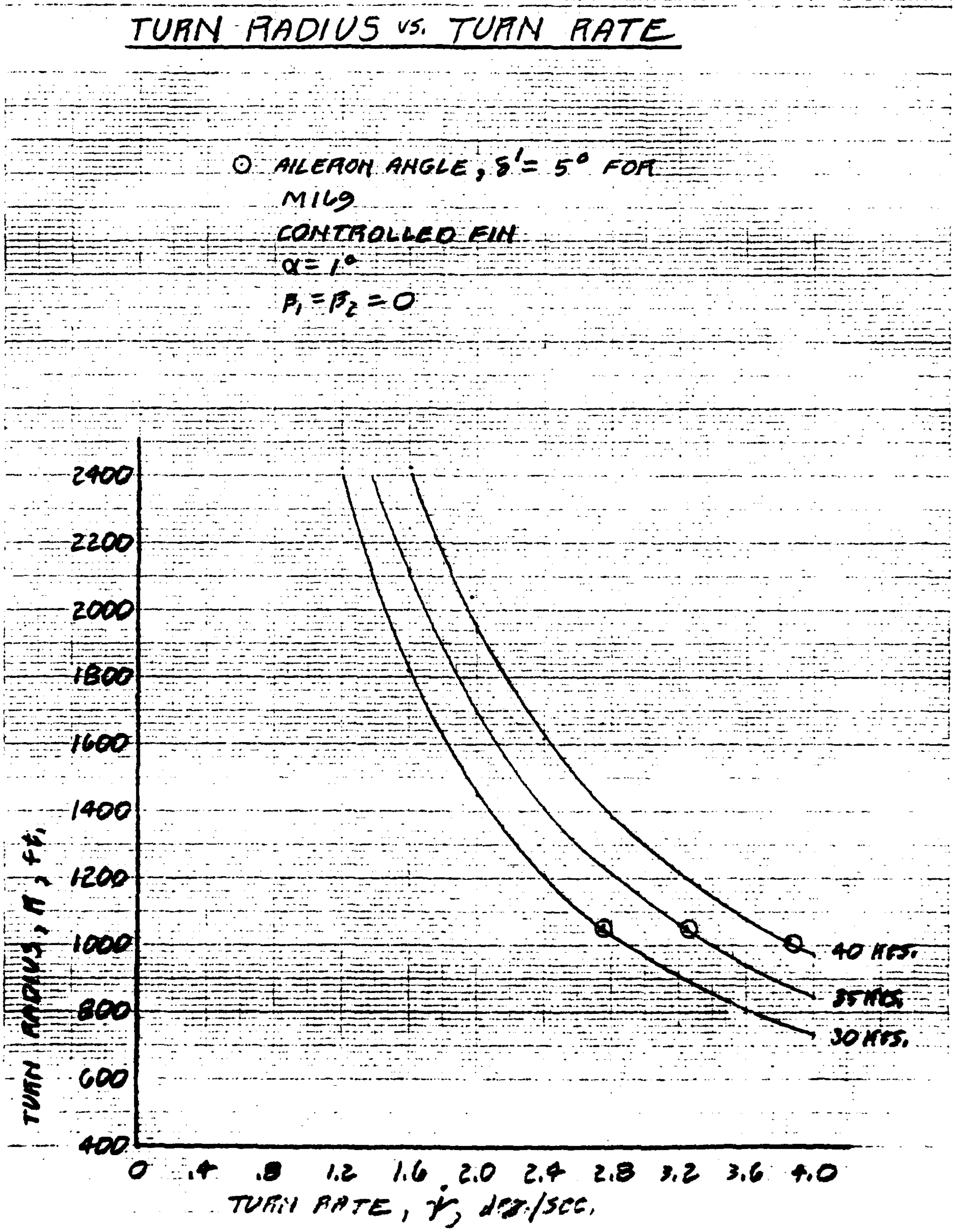

FIGURE 3-42

MRW 10/29/80

M169 RUDDER ANGLE

CONTROLLED FIN $\beta_1 = \beta_2 = 0$ $a = 1°$

M169

L=117.79 LT
Δ=183.92 LT

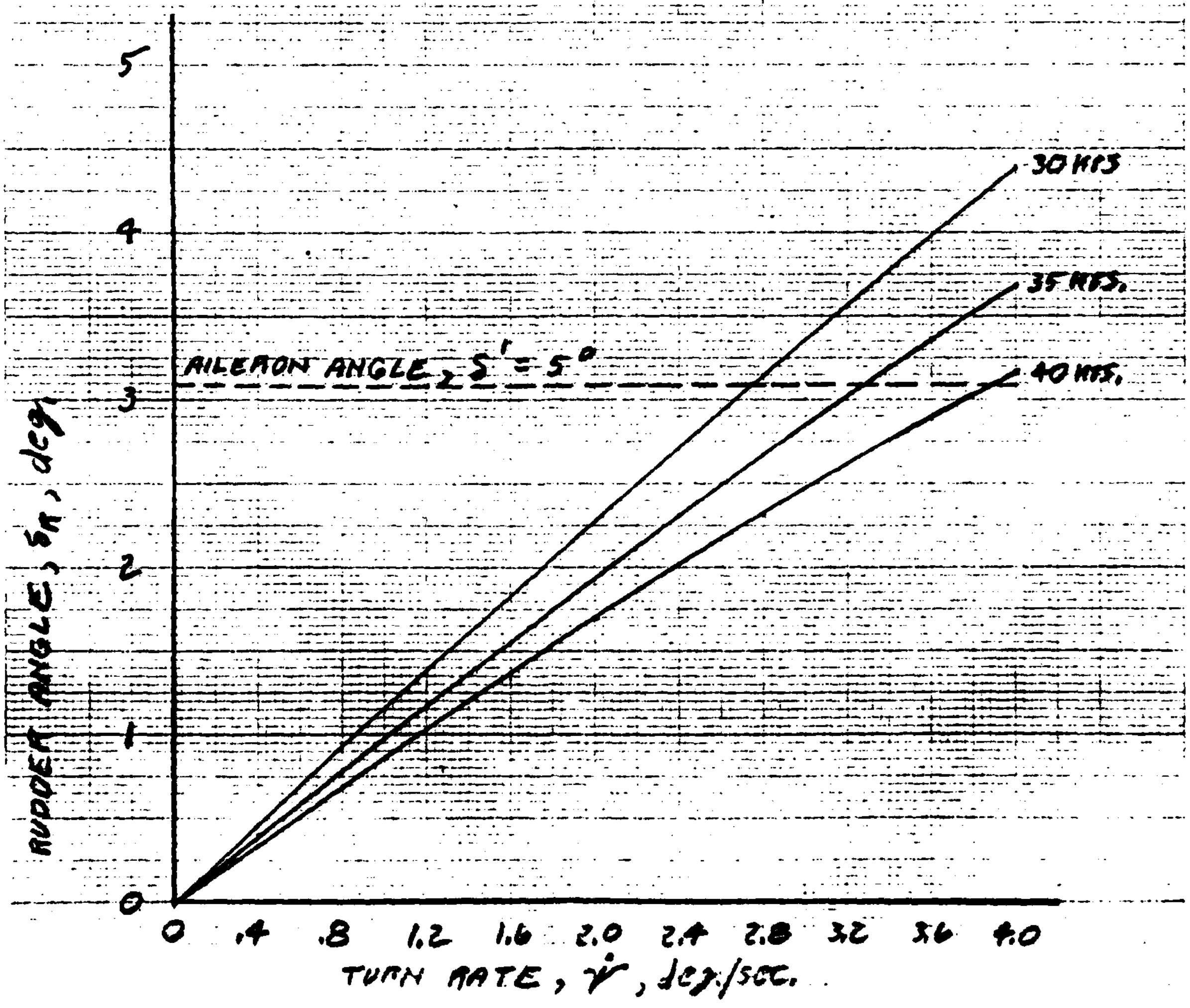

FIGURE 3-43

HRWP 10/20/80

CRAFT SIDESLIP ANGLE

AND

FIN ANGLE OF ATTACK

M169

CONTROLLED FIN $\alpha = 1^\circ$ $\beta_1 = \beta_2 = 0$

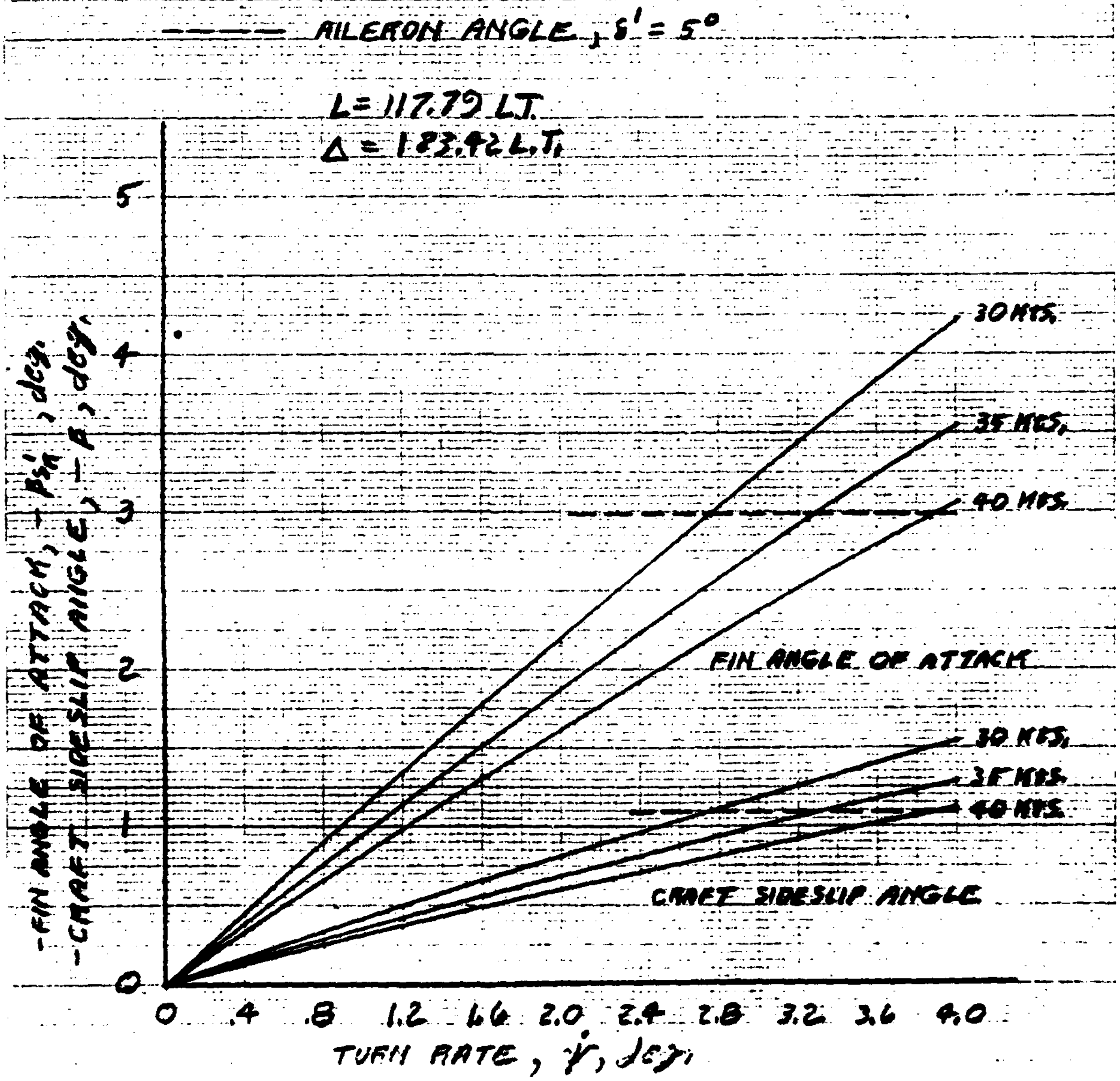

FIGURE 3-44

HRW 10/29/80

3.7 FOIL LIFT CHARACTERISTICS

3.7.1 Aft Foil- The aft foil dihedral increases the foil loading about 2% inboard and 1/2% outboard which is not significant to the geometry and environment problems presented by this foil. The lift characteristics were therefore calculated for a flat foil; strut effect and fwd foil/strut influence were neglected. Time constraints required neglecting the flap span gaps at mid-span and struts.

The spanwise load distributions were calculated by methods adapted from References 10, 11, and 12. There are simpler ways to estimate the lift curve slopes, but the load distributions are required for cavitation reasons. DeYoung's δ_1 denotes unit deflection of a full chord flap of arbitrary span extent. The estimated circulation distributions for pitch lift, lift control flap lift, and aileron lift are shown in Figures 3-45 and 3-46. The circulations incorporate a $K = C_{\ell_\alpha}/2\pi$ of .8993 for the 9% 16-series section.

The planimetered area of the pitch lift distribution of Figure 3-46 produced a pitch lift curve slope of:

$$\frac{C_L}{\delta_1} = C_{L_{\alpha\infty}} = 2A\int_0^1 \frac{G}{\delta_1}\,d\eta = 2 \times 7.659 \times .2728 = 4.1788 = 0.07293/\text{deg} \qquad (3.7.1\text{-}1)$$

which agrees with Figure 4 of Reference 10.

The planimetered area ofthe inboard panel distribution of Figure 3-46 produced a lift curve slope of:

$$C_L/\delta_1 = 2 \times 7.659 \times .13728 = 2.1029 = 0.03670/\text{deg} \qquad (3.7.1\text{-}2)$$

which is 1.3% higher than that of Figure 5 of Reference 11.

The zero lift angle for the 16-309 section is -2.024 degrees. Taking the outboard foil panels, where the incidence is zero, as the angular reference for the foil, Equations 3.7.1-1 and 3.7.1-2 identify the residual lift as:

$$C_{L_{O\alpha}} = 0.07293 \times 2.024 + 0.0367 \times 1.85 = 0.1476 + 0.0679 = 0.2155 \qquad (3.7.1\text{-}3)$$

AFT FOIL CIRCULATION DISTRIBUTION

SPAN STATION η	PITCH LIFT $\frac{G}{\delta_1}$	PITCH LIFT $\frac{c_l}{C_L}$	INBD. PANEL $\frac{G}{\delta_1}$	INBD. PANEL $\frac{c_l}{C_L}$	AILERON LIFT $\frac{G}{\delta_1}$	AILERON LIFT $\frac{c_l}{C_L}$	AILERON LIFT $\eta\frac{G}{\delta_1}$
0	.3162	1.1591	.2707	1.9719	0	0	0
.1950	.3139	1.1507	.2582	1.8808	.1852	.9358	.0361
.3827	.3063	1.1228	.2015	1.4678	.2439	1.2324	.0933
.5570	.2916	1.0689	.0988	.7197	.2533	1.2799	.1411
.7071	.2660	.9751	.0393	.2863	.2375	1.1999	.1679
.8315	.2248	.8240	.0156	.1136	.2053	1.0372	.1707
.9239	.1650	.6048	.0152	.1109	.1550	.7832	.1432
.9808	.0878	.3218	.0135	.0983	.0843	.4261	.0827
1	0	0	0	0	0	0	0

$$c_l/C_L = \frac{G}{\delta_1} \Big/ \int_0^1 \frac{G}{\delta_1}\, d\eta$$

Pitch Lift: $(c_l/C_L)_a = \frac{G}{\delta_1}/.2728$

Inbd. Panel: $(c_l/C_L)_i = \frac{G}{\delta_1}/.13728$

Aileron: $(c_l/C_L)_{\delta'} = \frac{G}{\delta_1}/.19792$

$$\int_0^1 \eta \frac{G}{\delta_1}\, d\eta = .1041$$

$$C_{L_I}/\delta_1' = 2 \times 7.659 \times .10767 = 1.6493$$

$$C_{L_0}/\delta_1' = 2 \times 7.659 \times .09025 = 1.3824$$

FIGURE 3-45

NAW 10/17/80

AFT FOIL CIRCULATION DISTRIBUTION

K=.8993

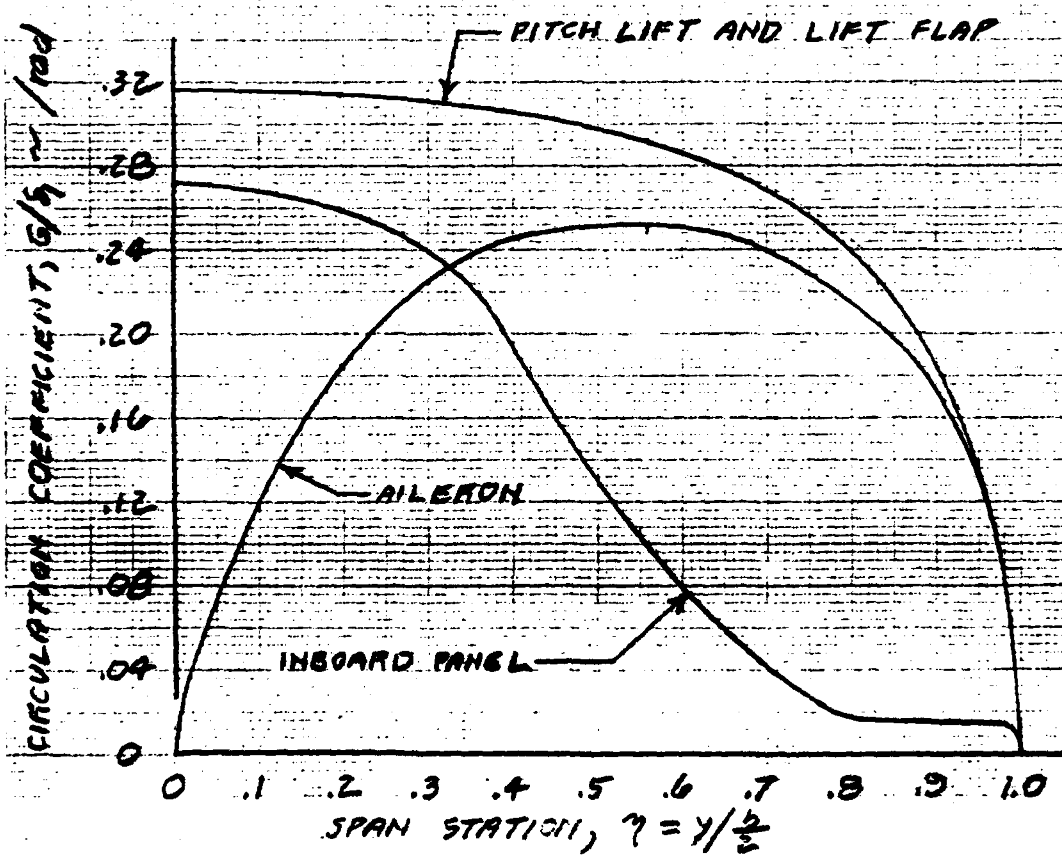

FIGURE 3-46

3.7.1 (Cont'd) (3.7.1-3)

For the .535 effectiveness of the 25% chord flap the lift control flap lift curve slope is:

$$C_{L_{\delta\alpha}} = .535 \times 4.1788 = 2.2357 = .03902/\text{deg.} \qquad (3.7.1\text{-}4)$$

The planimetered area of the aileron moment distribution of Figure 3-47 produced a moment slope of:

$$C_l/\delta_1 = A\int_0^1 \eta \frac{G}{\delta_1}\,dy \qquad (3.7.1\text{-}5)$$
$$= 7.659 \times .1041$$
$$= .7972$$

which is 1-1/2% higher than that of Figure 6 of Reference 12 for a linear extrapolation of the aspect ratio 4 and 8 curves of that figure, and 1.3% higher than the result provided by Equation (C10) and Table C5 of Reference 12.

$$\frac{C_L}{\delta_1} = 2 \times 7.659 \times .19792 = 3.0317 \qquad (3.7.1\text{-}6)$$

so the center of pressure for that distribution is:

$$\eta_{ac} = 2\,\frac{C_l/\delta_1}{C_L/\delta_1} = 2X\,\frac{.7972}{3.0317} = .5259 \qquad (3.7.1\text{-}7)$$

For the .535 flap effectiveness the rolling moment slope of Equation 3.7.1-5 is:

$$C_{l_{\delta'_\infty}} = .535 \times .7972 = .4265 = .007443/\text{deg.} \qquad (3.7.1\text{-}8)$$

From Equations 3.7.1-1, 3.7.1-3, and 3.7.1-4 the infinite depth lift curve for the aft foil is:

$$C_{L_\alpha} = C_{L_{b\alpha}} + (C_L)_{\alpha_\infty} + (C_L)_{\delta_\infty} \qquad (3.7.1\text{-}9)$$

AILERON MOMENT DISTRIBUTION

$K = .8993$

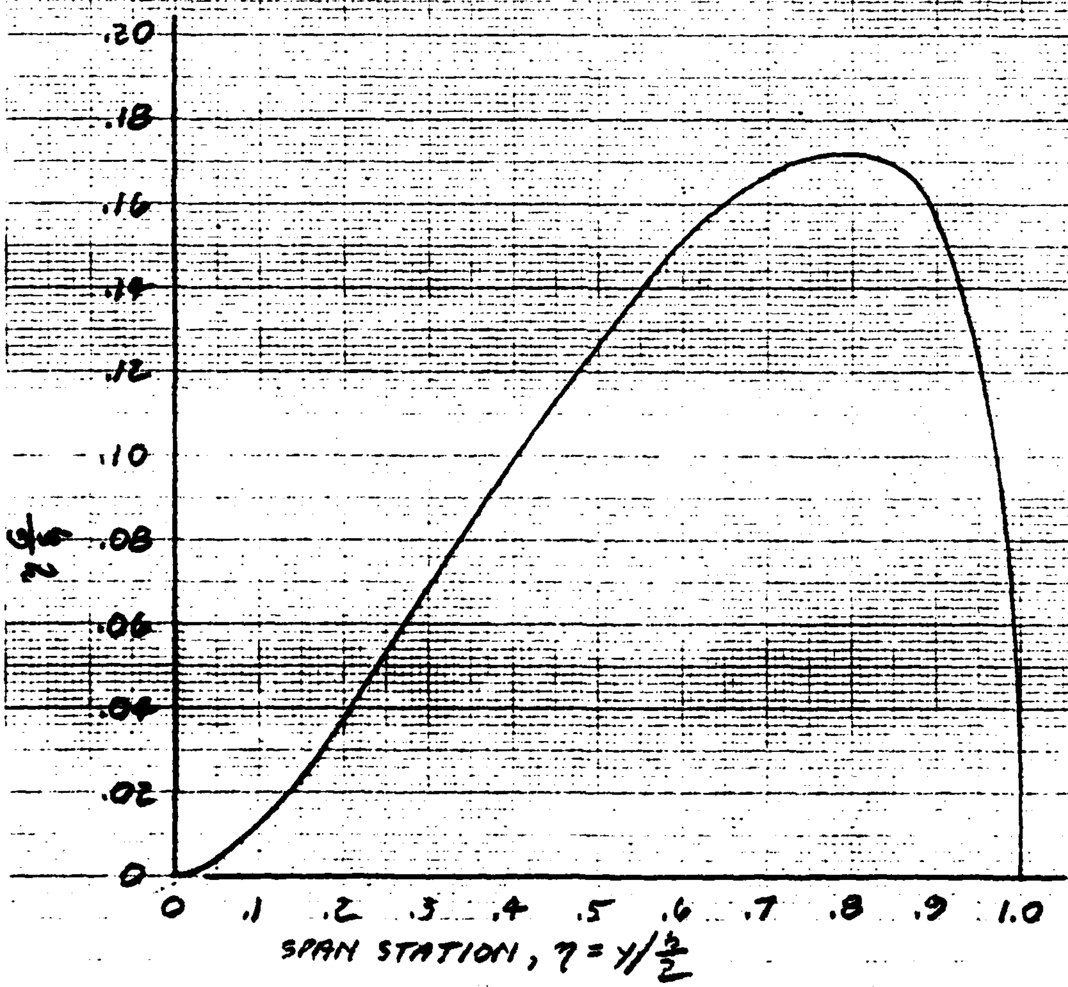

FIGURE 3-47

3.7.1 (Cont'd)

$$=.2155 + 4.1788\alpha + 2.235\delta$$
$$=.2155 + 4.1788\ (\alpha + .5350\delta\ )$$
$$=.2155 + .07293\ (\alpha^{o} + .5350\delta^{o})$$
$$= 2155 + .07293\alpha^{o} + .03902\ \delta^{o}$$

A 17.5% lift curve slope reduction is employed for 30-40 knots at 1 chord depth making the lift curve:

$$C_L = .1778 + 3.4475\alpha + 1.8444 \qquad (3.7.1\text{-}10)$$
$$= .1778 + .06017\alpha^{o} + .03219\ \delta^{o}$$
$$= .1778 + 3.4475\ (\alpha + .5350\delta)$$
$$= .1778 + .06017\ (\alpha^{o} + .5350\delta^{o})$$

where α is measured at the outboard panels.

With the 17.5% free surface reduction the rolling moment of Equation 3.7.1-8 becomes:

$$C_{l_\delta}{}' = \frac{l}{q S_2 b} = .3519 = .006140/\text{deg.} \qquad (3.7.1\text{-}11)$$

$$C_{l_\delta}{}' = \frac{l}{q S l} = \frac{172.85 \times 36.38}{238.48 \times 58.51} \times .3519 = .45066 \times .3519^{o})$$
$$= .1586 = .002768/\text{deg.}$$

The lift coefficient distributions corresponding to the circulation distributions of Figure 3-46 are shown on Figure 3-48.

3.7.2 Forward Foil - The lift curve of Equation (3) of Reference 13 is employed here for the forward foil:

$$C_L = .2122 + 3.5935\ (\alpha + .4844\delta\ ) \qquad (3.7.2\text{-}1)$$
$$= .2122 + 3.5935\alpha + 1.7407\delta$$
$$= .2122 + .06271\ (\alpha^{o} + .4844\ \delta^{o})$$
$$= -2122 + .06271\alpha^{o} + .03038\ \delta^{o}$$

The local lift coefficient maximums and minimums of Equation (4) of Reference 13 are employed here for the cavitation characteristics:

$$(c_l/C_L)_\delta = (c_l/C_L)_i = 1.2/.7 \qquad (3.7.2\text{-}2)$$
$$(c_l/C_L)_\alpha = 1.16/.82$$

LIFT COEFFICIENT DISTRIBUTION

AFT FOIL

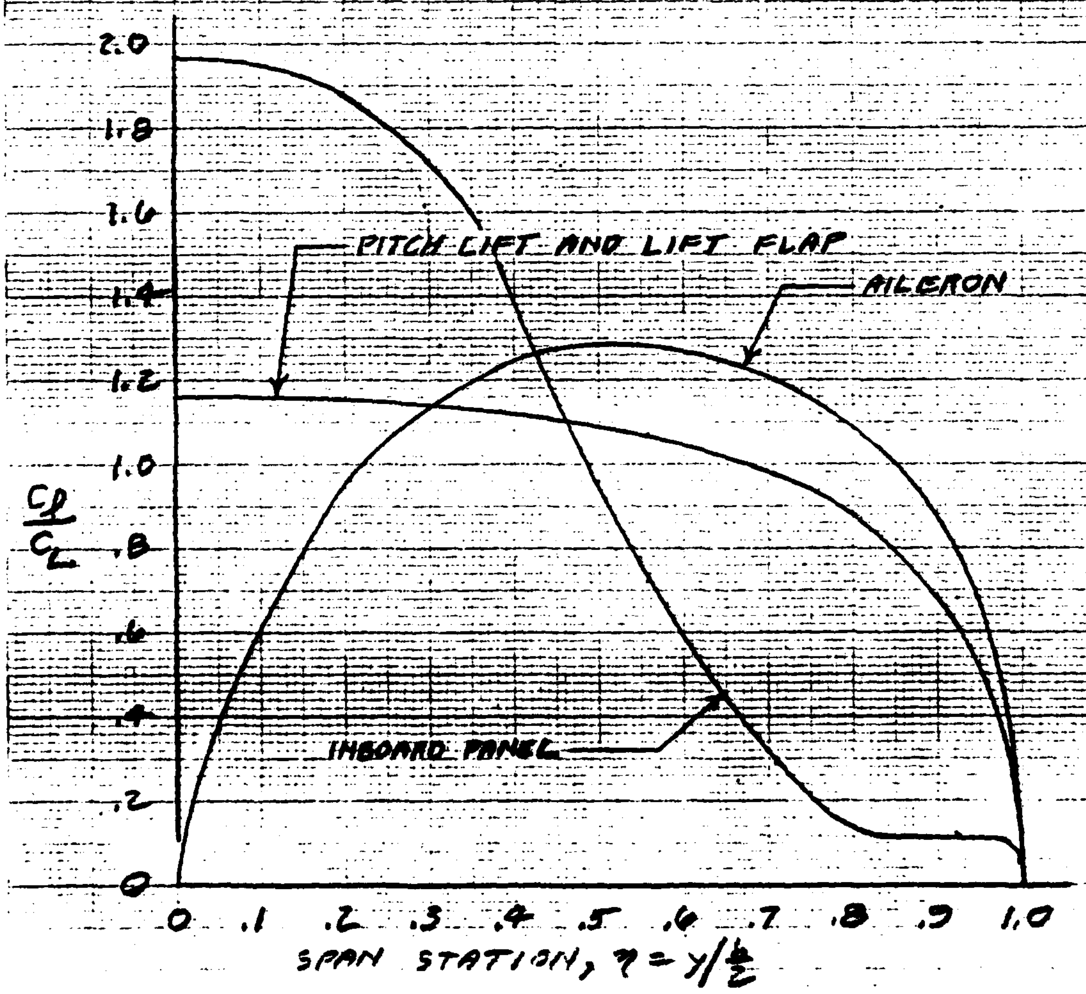

FIGURE 3-48

3.8 FOIL CAVITATION

3.8.1 Aft Foil - The Section α - δ cavitation corridor is defined by Equation 3.3.8.4-16 of Reference 15. Previous three dimensional applications of that equation have been limited to flaps of practically full span and time does not permit a rigorous exmaination of the distinctive problems presented by the lift distributions of Figures 3-46 and 3-48. In particular, the examination here is limited to the mid and 75% span stations which are intuitively considered to present the critical cavitation problems.

Equation 3.3.8.4-16 of Reference 13 defines the α - δ corridor as:

$$\sqrt{s} = \frac{v}{V} \pm \frac{\Delta v/V}{C_{l_{i_{ref}}}} C_{l_{i_{eff}}} \pm \frac{\Delta v_a'}{V} (C_l)_\alpha \pm \left(\frac{\Delta v_a'}{V} + \zeta\Omega\right)(C_l)_\delta \qquad (3.8.1\text{-}1)$$

At mid-span the section lift coefficient due to pitch is:

$$(C_l)_\alpha = \left(\frac{C_l}{C_L}\right)_\alpha C_{L_\alpha} \alpha_{OL} - C_{l_{i_{eff}}} + \left(\frac{C_l}{C_L}\right)_\delta \frac{C_L}{\delta_1} i \qquad (3.8.1\text{-}2)$$

where:

$\alpha_{OL} = \alpha - \alpha_{C_L = 0}$

$\alpha^\circ_{OL} = \alpha^\circ + 2.024$

i = incidence for mid-span foil portion

$i^\circ = 1.85$

At mid-span the section lift coefficient due to lift flap deflection is:

$$(C_l)_\delta = \left(\frac{C_l}{C_L}\right)_\delta C_{L_\delta} \delta \qquad (3.8.1\text{-}3)$$

With Equations 3.8.1-2 and 3.8.1-3 the three dimensional version of Equation 3.8.1-1 for the mid-span station, where the ailerons have no influence, becomes:

$$\sqrt{s} = \frac{v}{V} \pm \left(\frac{\Delta v/V}{C_{l_{i_{ref}}}} - \frac{\Delta v_a'}{V}\right) C_{l_{i_{eff}}} \pm \frac{\Delta v_a'}{V}\left(\frac{C_l}{C_L}\right)_\delta \frac{C_L}{\delta_1} i \pm \frac{\Delta v_a'}{V}\left(\frac{C_l}{C_L}\right)_\alpha C_{L_\alpha} \alpha_{C_L = 0}$$

$$\pm \frac{\Delta v_a'}{V}\left(\frac{C_l}{C_L}\right)_\alpha C_{L_\alpha} \alpha \pm \left(\frac{\Delta v_a'}{V} + \zeta\Omega\right)\left(\frac{C_l}{C_L}\right)_\delta C_{L_\delta} \delta$$

$$= \frac{v}{V} \pm \left(\frac{\Delta v/V}{C_{l_{i_{ref}}}} - \frac{\Delta v_a'}{V}\right) C_{l_{i_{eff}}} \pm \left[\left(\frac{C_l}{C_L}\right)_\delta \frac{C_L}{\delta_1} i - \left(\frac{C_l}{C_L}\right)_\alpha C_{L_\alpha} \alpha_{C_L = 0}\right] \frac{\Delta v_a'}{V}$$

$$\pm \frac{\Delta v_a'}{V}\left(\frac{C_l}{C_L}\right)_\alpha C_{L_\alpha} \alpha \pm \left(\frac{\Delta v_a'}{V} + \zeta\Omega\right)\left(\frac{C_l}{C_L}\right)_\delta C_{L_\delta} \delta$$

3.8.1 (Cont'd) The 16-309 section parameters of Reference 14 and the planform parameters of section 3.7 of this report are summarized in Figure 3-49 and with those parameters Equation 3.8.1-4 reduces to: (3.8.1-5)

$$\sqrt{S} = \frac{\mathcal{V}}{V} \pm \left(.258 - \frac{\Delta v_a'}{V}\right) X .21 \pm \left[1.16 \times .06017 \times 1.85 + 1.16 \times .06017 \times 2.024\right] \frac{\Delta v_a'}{V}$$

$$\pm 1.16 \times .06017 \frac{\Delta v_a'}{V} \alpha^{\circ} \pm 1.16 \times .03219 \left(\frac{\Delta v_a'}{V} + \xi_r\right) \delta^{\circ}$$

$$= \frac{\mathcal{V}}{V} \pm .05418 \mp .21 \frac{\Delta v_a'}{V} \pm .27039 \frac{\Delta v_a'}{V}$$

$$\pm .069797 \frac{\Delta v_a'}{V} \alpha^{\circ} \pm .03734 \left(\frac{\Delta v_a'}{V} + \xi_r\right) \delta^{\circ}$$

$$= \frac{\mathcal{V}}{V} \pm .05418 \pm .06039 \frac{\Delta v_a'}{V} \pm .069797 \frac{\Delta v_a'}{V} \alpha^{\circ} \pm .03734 \left(\frac{\Delta v_a'}{V} + \xi_r\right) \delta^{\circ}$$

The pressure coefficient is related to the pitch and lift flap lift coefficients by:

$$S = 1 + \frac{P_s - P_v}{L/S}\left(C_{L_o} + C_{L_\delta}\delta + C_{L_\alpha}\alpha\right) \qquad (3.8.1\text{-}6)$$

$$= 1 + \frac{2.429}{1000}\left(0.1778 + .06017\alpha^{\circ} + 0.03219\delta^{\circ}\right)$$

$$= 1.43188 + .14615\alpha^{\circ} + .07819\,\delta^{\circ}$$

For any station on the chord, Equations 3.8.1-5 and 3.8.1-6 provide the lift flap angle for incipient cavitation as a quadratic function of the pitch angle. The station parameters required are taken from Table 3.3.8.4-V of Reference 14 and are presented here in Figure 3-49. The hinge parameters of Table 3.3.8-4-V have been changed to reflect the experimental susceptability to cavitation shown in Reference 14.

The cavitation corridor provided by Equations 3.8.1-5 and 3.8.1-6 is shown on Figure 3-50. The leading edge (L.E.) and hinge line (75%) boundaries are expected to indicate incipient cavitation. The only effective boundaries of Figure 3-50 are expected to be the 60% and 70% chord boundaries, however the stations between 60% and 1-1/4% chord have not been checked.

The speed grid of Figure 3-50 is from Equation 3.7.1-10:

CAVITATION PARAMETERS

SECTION AND PLANFORM

AFT FOIL

PARAMETER	VALUE	
$\alpha_{C_\ell=0}$	−2.024 deg.	
$C_{\ell_{i\,eff}}$	.21	
$(\Delta v/V)/C_{\ell_{i\,ref}}$	.258	
Mid-Span i	1.85 deg.	
C_{L_0}	.1778	
$C_{L_\alpha}{}^{\circ}$	.06017	
$C_{L_\delta}{}^{\circ}$	.03219	
$C_{L_{\delta'}}^{\circ}$ (on semi-span)	.02335	
Inbd. C_L/δ_i /deg.	.030262	
Inbd. C_L/δ'_i /deg.	.023746	
Outbd. C_L/δ'_i /deg.	.019904	
	Mid-Span	Mid-Semi-Span
$(C_\ell/C_L)_\alpha = (C_\ell/C_L)_\delta$	1.16	1.09
$(C_\ell/C_L)_i$ (Inbd.)	1.97	.95
$(C_\ell/C_L)_{\delta'}$	0	1.28

CHORD STATIONS

	L.E.	1.25%	60%	70%	75%
v/V	.569	1.021	1.106	1.099	1.087
$\Delta v_a'/V$	2.914	1.354	.121	.083	.065
$\Delta v_a'/V + 3\Omega$	1.5948	.752	.213	.276	.715

FIGURE 3-49

3.8.1 (Cont'd)

$$C_L = \frac{L/S}{g} = .1778 + .06017\alpha^{\circ} + .03219\,\delta^{\circ} = \frac{1000}{2.0387 V_k^2} \quad (3.8.1\text{-}7)$$

$$\delta^{\circ} = \frac{10944}{V_k^2} - 5.5234 - 1.8692\,\alpha^{\circ}$$

$$= 1.3166 - 1.8692\,\alpha^{\circ} \quad @ \text{ 40 Knots}$$

$$= 6.6366 - 1.8692\,\alpha^{\circ} \quad @ \text{ 30 Knots}$$

At the mid-semi-span station the section lift coefficient due to ailerc deflection is:

$$(C_\ell)_{\delta'} = \left(\frac{C_\ell}{C_L}\right)_{\delta'} C_{L_{\delta'}}\,\delta' \quad (3.8.1\text{-}8)$$

The section lift coefficients of Equations 3.8.1-2 and 3.8.1-3 remain the same in form though the C_ℓ/C_L ratios change. Equation 3.8.1-4 remains the same except for the addition of the term of Equation 3.8.1-8. Then for the parameters of Figure 3-49 the cavitation at the 75% span station is described by:

$$\sqrt{S} = \frac{v}{V} \pm \left(.258 - \frac{\Delta v_a'}{V}\right) \times .21 \pm \left[1.09 \times 0.30262 \times 1.85 + 1.09 \times .06017 \times 2.024\right] \frac{\Delta v_a'}{V}$$

$$\pm 1.09 \times .06017 \frac{\Delta v_a'}{V}\alpha^{\circ} \pm \left(\frac{\Delta v_a'}{V} + \delta_{\sim}\right) \times 1.09 \times .03219\,\delta^{\circ}$$

$$\pm \left(\frac{\Delta v_a'}{V} + \delta_{\sim}\right) \times 1.28 \times .02335\,\delta'^{\circ} \quad (3.8.1\text{-}9)$$

$$= \frac{v}{V} \pm .05418 \mp .21 \frac{\Delta v_a'}{V} \pm .19377 \frac{\Delta v_a'}{V}$$

$$\pm .06557 \frac{\Delta v_a'}{V}\alpha^{\circ} \pm .035087\left(\frac{\Delta v_a'}{V}\,\delta_{\sim}\right)\delta^{\circ} \pm .029888\left(\frac{\Delta v_a'}{V} + \delta_{\sim}\right)\delta'^{\circ}$$

$$= \frac{v}{V} \pm .05418 \mp .01623 \frac{\Delta v_a'}{V} \pm .06558 \frac{\Delta v_a'}{V}\alpha^{\circ} \pm .035087\left(\frac{\Delta v_a'}{V} + \delta_{\sim}\right)\delta^{\circ} \pm .029965\left(\frac{\Delta v_a'}{V} + \delta_{\sim}\right)\delta'$$

$$\delta'^{\circ} = 33.458\,\frac{\pm\sqrt{S} \mp \frac{v}{V} - .05418 + .01623 \frac{\Delta v_a'}{V}}{\frac{\Delta v_a'}{V} + \delta_{\sim}} - 2.1942\,\frac{\Delta v_a'/V}{\frac{\Delta v_a'}{V} + \delta_{\sim}}\,\alpha^{\circ} - 1.1739\,\delta^{\circ}$$

The result is indeterminate without some constraint upon α and δ. The turn equations provide that constraint in the turn but here the cavitation boundaries are illustrated for straight and level flight where α and δ are related by Equation 3.8.1-7.

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3.8.1 (Cont'd) For a flap angle related to the craft pitch, α , by:

$$\delta^{\circ} = 31.065 \frac{L/S}{q} - 5.5239 - 1.8632\,\alpha^{\circ}$$

Equation 3.8.1-9 can be written:

$$\delta'^{\circ} = \pm \frac{33.458}{\frac{\Delta v_g'}{V} + \zeta\Omega}\sqrt{S} - 36.467\frac{L/S}{q} + 33.458 \times \frac{.01623\left(\frac{\Delta v_g'}{V} - 3.3383\right) \mp \frac{v}{V}}{\frac{\Delta v_g'}{V} + \zeta\Omega}$$

$$+ 6.4839 + 2.1972\left(1 - \frac{\Delta v_g'/V}{\frac{\Delta v_g'}{V} + \zeta\Omega}\right)\alpha^{\circ} \qquad (3.8.1\text{-}10)$$

and for a one degree craft pitch and a 1,000 psf dynamic lift loading on the foil:

$$\delta'^{\circ} = 6.4839 \pm \frac{33.458}{\frac{\Delta v_g'}{V} + \zeta\Omega}\sqrt{S} - \frac{12876}{V_K^2} - 33.458 \times \frac{.01623\left(3.3383 - \frac{\Delta v_g'}{V}\right) \pm \frac{v}{V}}{\frac{\Delta v_g'}{V} + \zeta\Omega} \qquad (3.8.1\text{-}11)$$

$$+ 2.1942\left(1 - \frac{\Delta v_g'/V}{\frac{\Delta v_g'}{V} + \zeta\Omega}\right)$$

where: $\sqrt{S} = \sqrt{1 + \frac{2429}{q}} = \sqrt{1 + \frac{8556.7}{V_K^2}}$

Equation 3.8.1-11 is shown on Figure 3-51 where the significance of the boundaries is inferred from the section experience of Reference 14; these results have not been compared with the prototype experience.

3.8.2 Forward Foil - The PCH prototype cavitation data available is reviewed in Reference 13 and Figure A31 of that reference is presented here as Figure 3-52. The theoretical hinge line boundary of Reference 13 has been revised and a new theoretical leading edge boundary, of unidentified chord station, added to reflect the experimental section data review of Reference 14.

AFT FOIL CAVITATION BOUNDARIES

MID-SEMI-SPAN

$\alpha = 1^{\circ}$

$L/S = 1000$ psf

$P_s - P_v = 2425$ psf

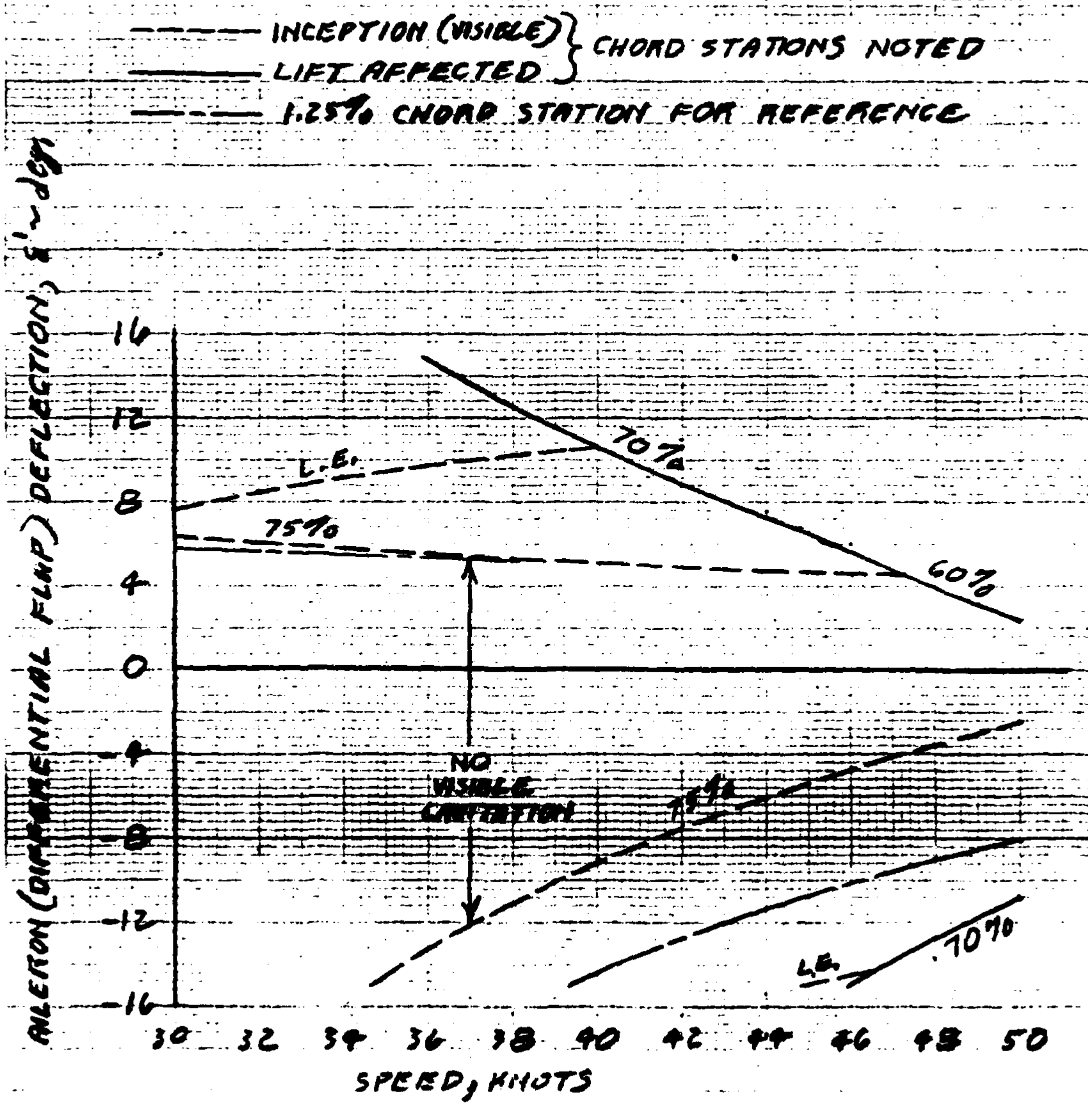


FIGURE 3-51

FWD. FOIL α-δ CAVITATION CORRIDOR

L/S = 1378 psf
$P_s - P_v$ = 2603

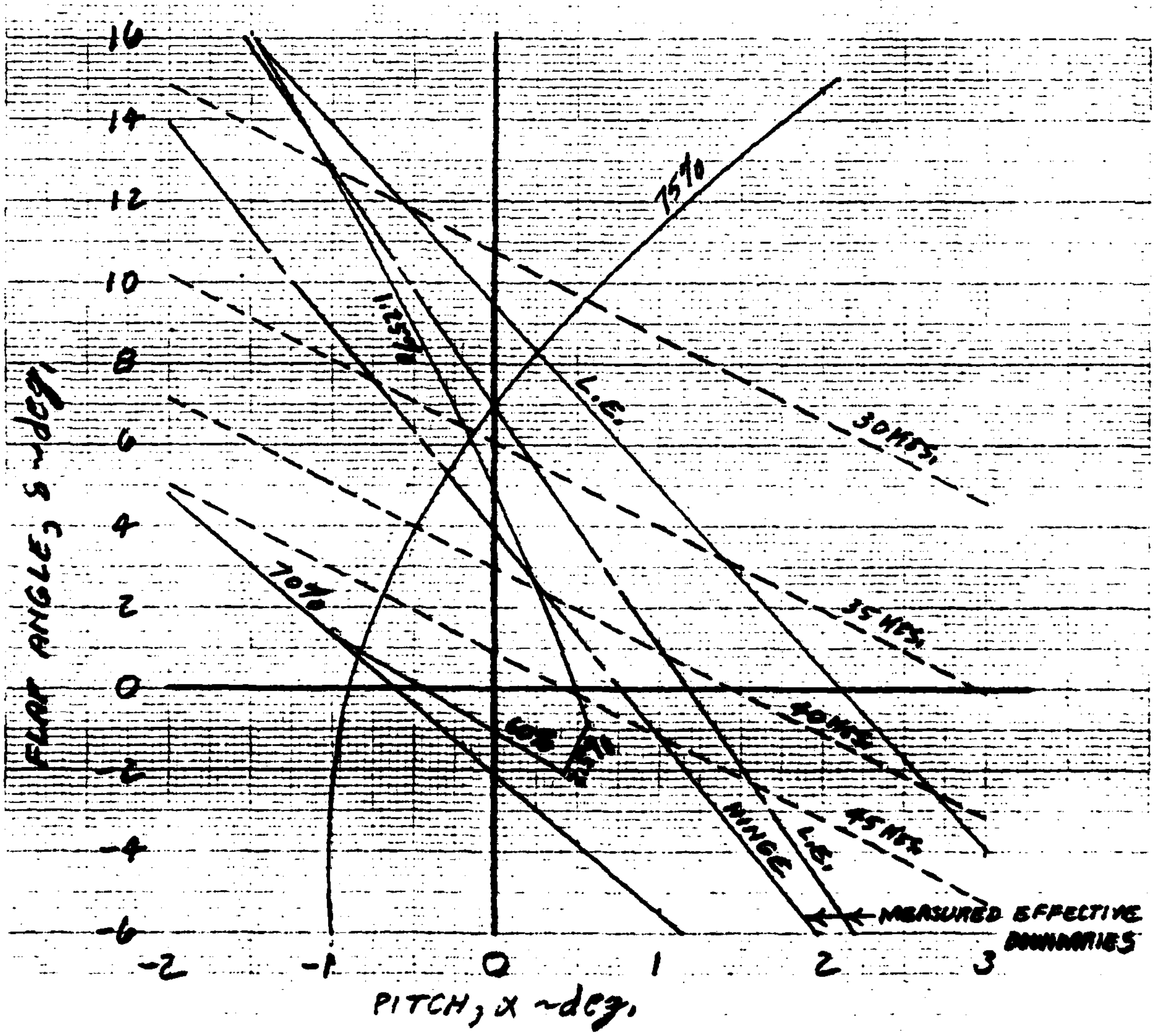


FIGURE 3-52

MAW 9/11/80

3.8.2 (Cont'd) The measured effective leading edge boundary of Figure 3-52 is ill-defined by the data, in large part because the effect of moderate leading edge cavitation is not very significant. No $\alpha - \delta$ combinations in the range of Figure 3-52 is expected to produce any significant leading edge cavitation.

The experimental hinge line boundary of Figure 3-52 was well defined and was associated with substantial lift effects. The shape of that boundary, however, has not yet been accounted for by any creditable variation on the cavitation parameters and there remains a possibility that it measures structural or ventilation effects.

3.9 Transmission - The analysis of the transmission system was primarily a determination of the bearing lives under the following assumed operation schedule:

OPERATION CONDITION	TIME %	ENGINE HP	INPUT SHAFT RPM	INPUT SHAFT TORGUE LB.-IN
TAKE-OFF + HIGH SPEED FOILBORNE	10	4110	4200	61,700
CRUISE-MAX RANGE	70	3600	3859	58,800
IDLING	20	30	673	2,810

The results of the bearing analysis are contained in Appendix 'A'. The four critical bearings have B-10 lives of less than 1000 hours in standard steel. The use of CEVM material will increase their life three-fold, thereby providing a reasonable mean-time between failure (MTBF). It is recommended that these bearings be replaced by ones made of that material.

The resulting differences between the conclusions of Appendix 'A' and Reference 3 are due primarily to the change in the operations profile to that shown above, which includes the increased thrust required for the buoyancy/fuel tank installation.

3.9 (Cont'd) As the data available on the existing transmission shafting and gears was incomplete, only a minimal effort could be expended to analyze the components. From this information, it is presumed that these components are satisfactory as it is understood that an analysis was performed prior to uprating the Proteus engines.

The investigation into the transmission spiral bevel gear design revealed that the gearsets were initially designed to operate at the engine torque limit of 61,700 lb. in. (4110 HP @ 4200 RPM) to the upper bevel gearbox. Although the transmission system has normally operated below a torque of 49,000 lb. in. (3900 HP @ 5000 RPM) it is felt that the increase to 61,700 lb. in. for short periods of time should not prove detrimental to the bevel gear sets. However, the disconnect coupling was designed for the following operating conditions:

Max Load 20% Time 49,000 lb. in.-3900HP @ 5000 RPM
Load 80% Time 39,075 lb. in.-3100HP @ 5000 RPM
Stall Torgue without permanent deformation 102,000 lb. in.

As the maximum design load is less than the required 61,700 lb. in. for 4110 HP @ 4200 RPM, it will be necessary to replacé or redesign this coupling, if the coupling information available truly reflects the actual installation.

3.9.1 Subsequent to the foregoing investigation it has been ascertained that DTNSRDC (HYSTU) has initiated a comprehensive analysis of the PCH-1 transmission as currently installed. Upon completion and review of the results of this investigation, its impact upon Design M169 will be assessed.

SECTION 4

WEIGHT AND STABILITY

4.0 The baseline condition of the existing PCH-1 Mod 1 was derived from the weight statement dated 2-15-73, Boeing Document D-311-18000-1, reproduced herein as Figure 4-1. One objective of the investigation was to establish a new Light Ship weight and intact stability which would include the addition of the buoyancy/fuel tank and its associated systems.

4.1 Weight - The final estimate of 22.2 long tons for the tank, its subsystems and associated attachment hardware, 7.2 long tons for the B/F tank support strut, and 9.68 long tons for hull modifications result in a new Light Ship weight of 146.96 long tons against the 107.38 long tons for the existing PCH-1 as shown in Reference 26. The revised weight summary is shown in Figure 4-2. Tank weight calculations are detailed in Reference 26.

It is to be noted that 1.39 tons of armament have been deleted from Figure 4-2 in order to partially compensate for the weight of the added structure. Additional load reductions will be required to meet the dynamic lift requirements for satisfactory performance.

4.2 Stability

4.2.1 Intact Stability - The addition of a positively buoyant body under the hull of the PCH-1 Mod 1 will detract from the vessel's intact stability. Design M169, with its longer range, is likely to be subjected to unplanned heavy weather during its full scale trials; therefore, the safety of the ship and crew must be paramount in setting the limits for the allowable positive buoyancy of the fuel tank.

An intact stability analysis was performed to determine the safe upper limits of tank buoyancy. The calculations followed the procedures outlined

GROUP WEIGHT STATEMENT PC(H)-1 (MOD I) Date 2-15-73

Description	Weight (Tons)	VCG Above Base	Moments	Center of Gravity (ft) From FP LCG	From FP Moments	+ Stbd. of C TCG	+ Stbd. of C Moments
GROUP 1 HULL STRUCTURE	33.19	10.70		63.50		-	
2 PROPULSION	17.38	7.12		91.72		-	
3 ELECTRIC PLANT	6.09	8.67		76.62		-	
4 COMMUNICATIONS & CONTROL	2.70	21.21		38.07		-	
5 AUXILIARY SYSTEMS	8.19	10.19		59.43		-	
6 OUTFIT AND FURNISHINGS	9.10	10.84		48.85		-	
7 ARMAMENT	1.39	15.14		51.51		-	
FOIL SYSTEM	21.52	-3.75		63.61		-	
SHIP LIGHT CONDITION A (FOILS DOWN)	99.56	7.15		63.39		.112	
LOADS (MINIMUM TRIALS OPERATING)	5.67	8.85		50.10		.2365	
FUEL OIL (MINIMUM OPERATING)							
TANK 3-11-0-F (800 NON-USABLE + 900 = 1700 GAL)	5.39	1.56		60.5		0	
3-13-0-F (200 NON-USABLE + 600 = 800 GAL)	2.54	1.45		68.2		0	
SHIP IN MINIMUM OPERATING CONDITION B	113.16	6.84		62.69		.1111	
FOIL SYSTEM BUOYANCY BELOW FWL	-4.28	-12.0		74.1		0	
SHIP IN MIN. OPER. COND. (DYNAMIC LIFT)	108.88	7.58		62.25		.1155	
LOADS (DESIGN FULL LOADS)	6.04	8.81		49.73		.1243	
FUEL OIL (95% CAPACITY)							
TANK 3-11-0-F (3871 GAL)	12.27	2.5		60.5		0	
3-13-0-F (2628 GAL)	8.33	2.6		68.2		0	
SHIP IN FULL LOAD CONDITION D	126.20	6.48		62.77		.095	
FOIL SYSTEM BUOYANCY BELOW FWL	-4.28	-12.0		74.1		0	
SHIP IN FULL LOAD COND. (DYNAMIC LIFT)	121.92	7.12		62.37		.098	

16.1

D-311-18000-1

FIGURE 4-1

M-169

DESCRIPTION		WEIGHT (TONS)
Group 1-7	Craft	85.86
	Foil Systems	21.52
	Hull Modifications	9.68
	Buoyancy/Fuel Tank System	29.90
Ship Light Condition		146.96 L.T.
Loads (Minimum Trials Operating)		2.26
Fuel Oil (Minimum Operating)		
Tank 3-11-0-F		5.39
3-13-0-F		2.54
B/F Tank - Full Ballast & Residual Fuel		51.44
Ship in Minimum Operating Condition 'B'		208.59 L.T.
Buoyancy-Tank and Foil System		-73.90
Ship in Minimum Operating Condition (Dynamic Lift)		134.69 L.T.
Loads (Design Full Load)		3.23
Fuel Oil (95% Capacity)		
Tank 3-11-0-F		12.00
3-13-0-F		8.00
B/F Tank - Full Fuel & Residual Ballast		42.62
Ship in Full Load Condition 'D'		212.81 L.T.
Buoyancy-Tank and Foil System		-73.90
Ship in Full Load Condition (Dynamic Lift)		138.91 L.T.

FIGURE 4-2

4.2.1 (Cont'd) in Navy Design Data Sheet 079-1, "Stability and Buoyancy of U.S. Naval Surface Ships". The design requirement is that the ship be capable of meeting the gradient 80 knot beam wind criteria of this document. The detailed calculations are described in Reference 27.

Results of the intact stability investigation, which was performed using an assumed tank structural and subsystem weight of 29.9 long tons, indicate that the upper limit of net tank buoyancy, with the PCH-1 Mod 1 in Minimum Operating Condition, is about 11.82 long tons. With the ship in Full Load Condition, it is about 15.82 long tons.

In order to simplify the design of the fuel and ballast system, it is recommended that the 11.82 ton buoyancy limit be established as the the design requirement for any condition of ship loading, thereby eliminating the possibility of unsafe ballast conditions as a result of system malfunction or operator error.

As the wind velocity in which the craft will remain stable is a function of the amount of liquid remaining in the buoyancy/fuel tank, Figure 4-3 is presented to indicate this relationship. However, this curve may also vary considerably due to the location of the craft's V.C.G. and should not be interpreted, therefore, as permissable operating conditions.

4.2.2 Damaged Stability - The damaged stability of the Design M169 was investigated for 56 conditions of flooding. From this review, it is apparent that the craft is more susceptible to stability problems when flooded aft than forward.

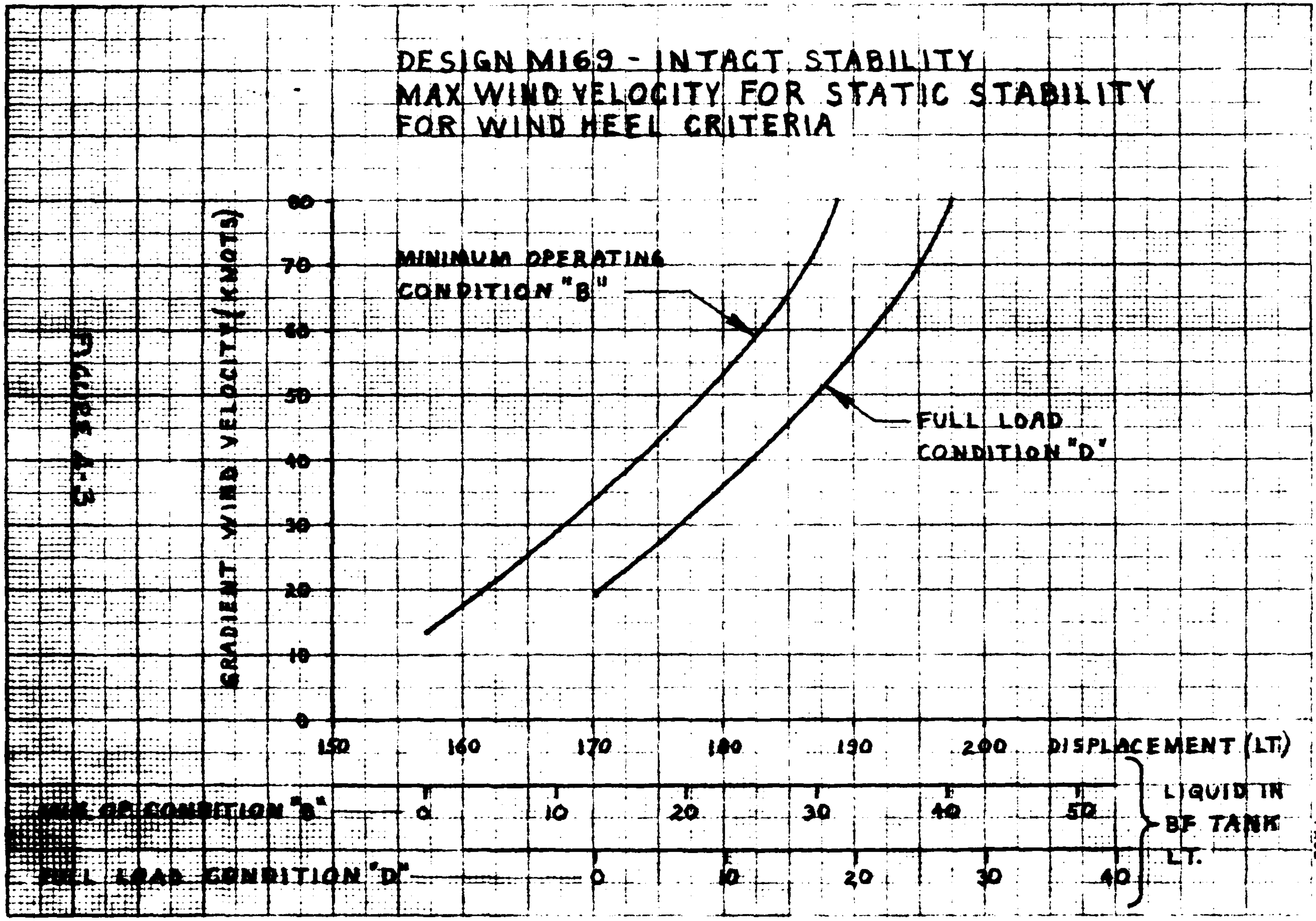

DESIGN M169 - INTACT STABILITY
MAX WIND VELOCITY FOR STATIC STABILITY
FOR WIND HEEL CRITERIA
GRADIENT WIND VELOCITY (KNOTS)
80
70
60
50
40
30
20
10
0
MINIMUM OPERATING
CONDITION "B"
FULL LOAD
CONDITION "D"
150
160
170
180
190
200
DISPLACEMENT (LT)
LIQUID IN
BF TANK
LT.
MIN OP CONDITION "B"
0
10
20
30
40
50
FULL LOAD CONDITION "D"
0
10
20
30
40

FIGURE 4-3

SECTION 5

BUOYANCY/FUEL TANK

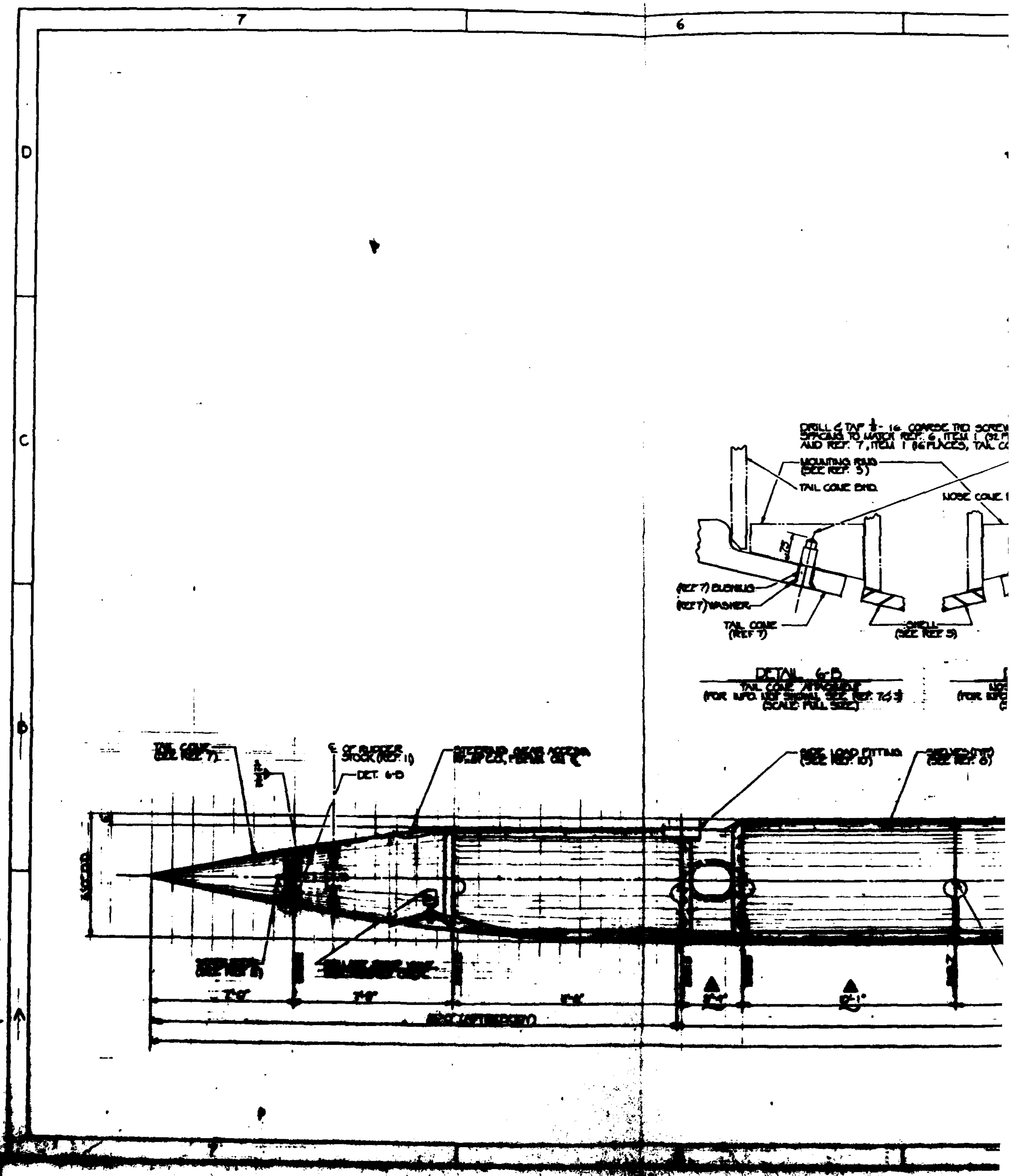
5.0 General Description - The buoyancy/fuel tank is a body of revolution with tapered ends supported by the B/F tank support strut below the existing forward and aft foil systems. The tank is sub-divided into six fuel/ballast cells, five buoyancy, and one steering gear compartment as shown on Figure 5-1. The outside diameter of the tank is six feet and the overall length is 100 feet of which 63'-1" is the parallel midbody. The forebody shape was specified by DTNSRDC ltr. 1159:JRM 3910 dated 2 Sept. 1981.

The fuel/ballast cells are each fitted with a diaphragm separating the two mediums to prevent fuel contamination.

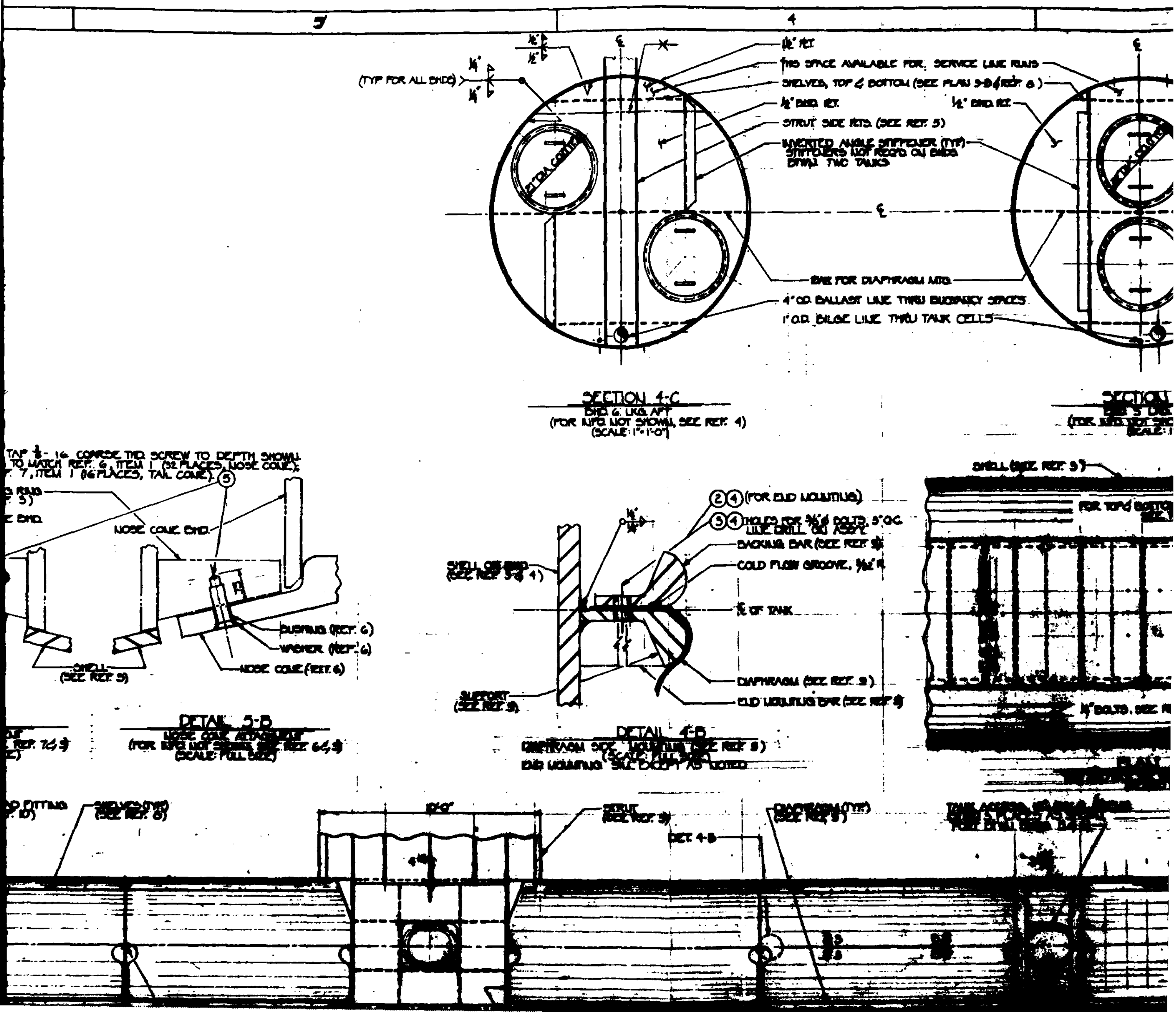
5.1 Capacitites - The estimated total volume of displacement of the buoyancy/fuel tank is 2194 cubic feet, or 68.39 long tons. Of this, 38.51 long tons has been identified as usable diesel fuel. It is estimated that fully loaded with diesel fuel, the tank will provide approximately 3.57 tons of positive buoyancy, well below the 11.82 critical for stability purposes. (See Section 4.2). In the event that JP-5 fuel is used, the buoyancy would then be increased by 1.01 tons to 4.58 tons. For conservatism, the 3.57 tons has been used for the stability calculations in Reference 27.

In the fully ballasted condition, the cells have an equivalent capacity of 49.63 tons of sea water which results in the tank having approximately 5.25 tons of negative buoyancy. This is offset, however, by the assumption that the hull fuel of approximately 20 tons is being burned off, resulting in a net decrease in dynamic lift requirements.

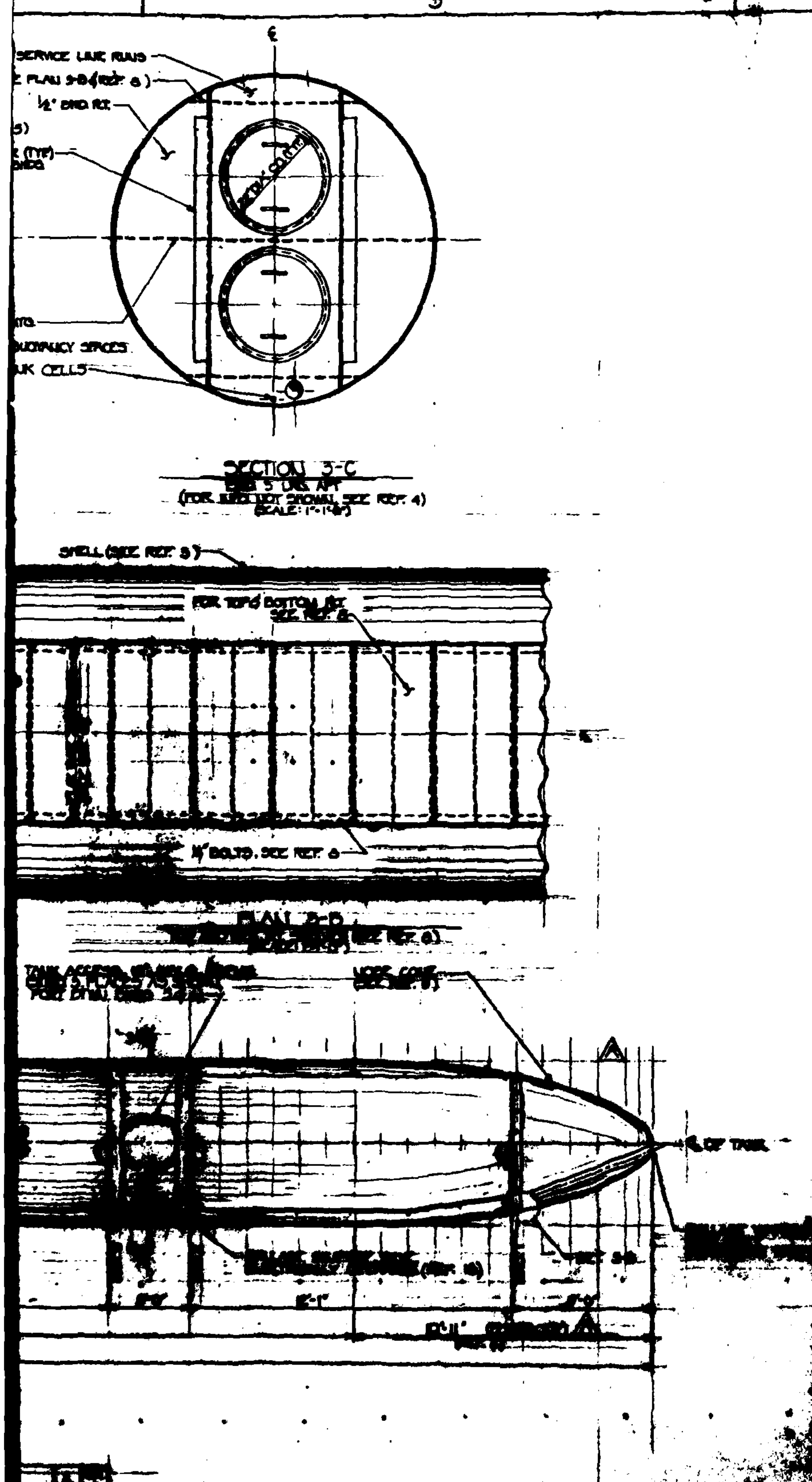
The derivation of the capacities of the individual tanks is presented in Figure 5-2 and the relationship between dynamic lift and buoyancy for two conditions is given in Figure 5-3.



7
6
D
C
B
MOUNTING RING
(SEE REF. 5)
TAIL CONE BHD.
NOSE CONE
(REF 7) BUSHING
(REF 7) WASHER
TAIL CONE
(REF 7)
SHELL
(SEE REF 5)
DETAIL 6-B
(SCALE FULL SIZE)
℄ OF RUDDER
STOCK (REF. 11)
DET. 6-B
SIDE LOAD FITTING
(SEE REF. 10)



5
4
(TYP FOR ALL BHDS)
1/2" RT.
THIS SPACE AVAILABLE FOR SERVICE LINE RUNS
SHELVES, TOP & BOTTOM
1/2" BHD. RT.
STRUT SIDE RTS. (SEE REF. 5)
INVERTED ANGLE STIFFENER (TYP)
STIFFENERS NOT REQ'D ON BHDS. BTWN. TWO TANKS
BAR FOR DIAPHRAGM MTG.
4" O.D. BALLAST LINE THRU BUOYANCY SPACES
1" O.D. BILGE LINE THRU TANK CELLS
SECTION 4-C
BHD 6 LKG. AFT
(FOR INFO NOT SHOWN, SEE REF. 4)
(SCALE: 1"=1'-0")
NOSE CONE BHD.
BUSHING (REF. 6)
WASHER (REF. 6)
NOSE CONE (REF. 6)
SHELL (SEE REF. 5)
DETAIL 5-B
NOSE CONE ATTACHMENT
(SCALE: FULL SIZE)
(FOR END MOUNTING)
BACKING BAR
COLD FLOW GROOVE
℄ OF TANK
SHELL OR BHD.
SUPPORT
DIAPHRAGM (SEE REF. 3)
END MOUNTING BAR
DETAIL 4-B
(SCALE: FULL SIZE)
END MOUNTING SIM. EXCEPT AS NOTED
SHELL (SEE REF. 3)
STRUT (SEE REF. 3)
DIAPHRAGM (TYP) (SEE REF. 3)
DET. 4-B

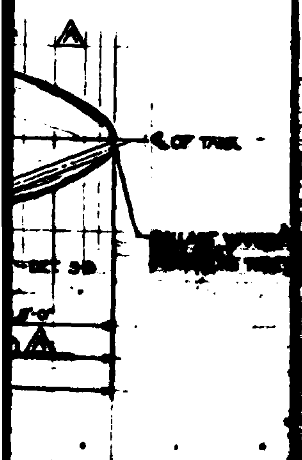


GENERAL NOTES

1. TANK MATERIAL TO BE HY-80 STEEL.
2. NOSE AND TAIL CONES TO BE MOLDED FIBERGLAS.
3. SHELL WELDS TO BE INSPECTED BY MAGNETIC PARTICLE OR LIQUID PENETRANT METHOD.
4. INTERIOR BULKHEAD WELDS TO BE CHECKED FOR TIGHTNESS WITH AIR HOSE AND LEAK DETECTOR SOLUTION.
5. EACH CELL TO BE INDIVIDUALLY PRESSURE TESTED TO IN ACCORD WITH REF. 6.
6. EXTERIOR SURFACES TO BE SAND BLASTED AND FINISHED IN VINYL ANTI-FOULING SYSTEM AS PER GEN. SPECS. FOR SHIPS OF THE U.S. NAVY, NAVSEA 0902-LP-018-2010, SEC. 631 OR EQUIV AS NOTED ON REF. 3.
7. INTERIORS TO BE FINISHED IN SPEC. DOD-P-23236 SYSTEM, CL. 1, 2 OR 4 FOR FUEL SPACES; CL. 1, 2 OR 4 FOR BALLAST SPACES; CL. 3 FOR VOIDS & ACCESS.
8. ADAPTER ASSEMBLIES THRU END PENETRATIONS SHALL BE PRE-ASSEMBLED, INDEXED, INSERTED INTO PRE-DRILLED HOLES AND WELDED TO BHD. PRIOR TO END INSTALLATION.
9. FOR WELDING PROCEDURES & MATERIAL, SEE REF. 4.

RESERVATIONS

1. GENERAL NOTE #6



GENERAL NOTES

1. [illegible] MATERIAL TO BE HY-80 STEEL.
2. [illegible] VL COVERS TO BE MOLDED FIBERGLAS.
3. [illegible] TO BE INSPECTED BY MAGNETIC PARTICLE [illegible] PENETRANT METHOD.
4. [illegible] WELDS TO BE CHECKED FOR TIGHTNESS [illegible] LEAK DETECTOR SOLUTION.
5. [illegible] BE INDIVIDUALLY PRESSURE TESTED TO [illegible]
6. [illegible] TO BE SAND BLASTED AND PAINTED [illegible] GEN. SPECS. [illegible] SEC. 631.
7. [illegible] SPEC. DOD-P-23236 [illegible] FUEL SPACES; [illegible] BALLAST SPACES; [illegible] 3 FOR VOIDS & ACCESS.
8. [illegible] ASSEMBLIES THRU END PENETRATIONS SHALL BE [illegible] INSERTED INTO PRE-DRILLED [illegible] WELDED TO [illegible] PRIOR TO END INSTALLATION.
9. FOR WELDING PROCEDURES & MATERIAL, SEE REF. 4.

RESERVATIONS

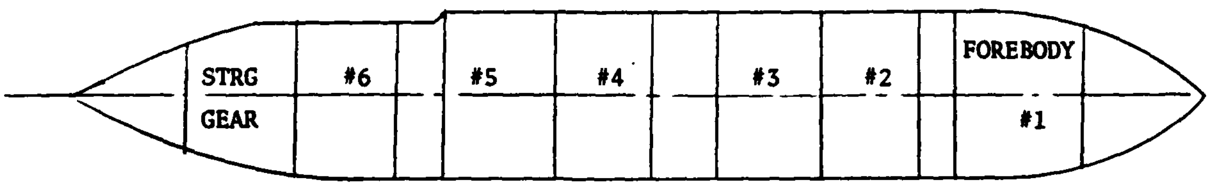
1. [illegible] NOTE 6.

A	A	[illegible] REVISED CONTR. [illegible] TO 69-1 [illegible] TITLE BLOCK.	[illegible]	[illegible]

M169

BUOYANCY/FUEL TANK CAPACITIES

TANK CAPACITIES - BUOYANCY



TOTAL DISPLACEMENT SW 68.39 LT.

VOLUME OF DISPLACEMENT 2393.66 FT^3

BUOYANCY/WEIGHT:

	Full Fuel Condition	Full Ballast Condition
Tank Weight	22.20 LT	22.20 LT
Unusable Fuel	1.81	1.81
Permanent Ballast	2.30	
Usable Fuel	38.51	
Net Ballast		49.63
Total Weight	64.82	73.64
Net Buoyancy	+ 3.57	-5.25

TANK CAPACITY DERIVATION

Figure 5.2
SH 1 of 3

B/F TANK - CAPACITIES & FULL FUEL/BALLAST FLUID WTS.

FUEL TANKAGE:

Tank	(1) Gross Volume (ft^3)	(2) Perm. Ballast Tank Bottom (ft^3)	(3) Ballast Trapped by Diaphragm (ft^3)	(4) Total Fuel (1)-[(2)+(3)] (ft^3)	(5) Unusable Fuel Tank Top (ft^3)	(6) Trapped by Diaphragm (ft^3)
Forebody #1	333	16	3	314	13	3
Midbody #2	321	10	3	308	10	3
#3	321	10	3	308	10	3
#4	279	9	3	267	9	3
#5	279	9	3	267	9	3
Afterbody #6	282	9	3	270	9	3
TOTALS	1815 ft^3	63 ft^3	18 ft^3	1734 ft^3	60 ft^3	18 ft^3

(7) Usable Fuel (4)-[(5)+(6)] ft^3	(8) Total Fuel (Lt) (4)÷43	(9) Usable Fuel (LT) (7)÷43	(10) Unusable Fuel (LT) (8) - (9)	(11) Total Perm. Ballast (LT) [(2)+(3)]÷35	(12) Full Fuel Cond. Fluid Wt. (LT) (8) + (11)	Tank
298	7.30	6.93	0.37	0.54	7.84	#1
295	7.16	6.86	0.30	0.37	7.53	#2
295	7.16	6.86	0.30	0.37	7.53	#3
255	6.21	5.93	0.28	0.34	6.55	#4
255	6.21	5.93	0.28	0.34	6.55	#5
258	6.28	6.00	0.28	0.34	6.62	#6
1656 ft^3	40.32 LT	38.51 LT	1.81 LT	2.30 LT	42.62 LT	TOTALS

TANK CAPACITY DERIVATION

Figure 5-2
SH 2 of 3

BALLAST TANKAGE:

Tank		(13) Gross Volume (ft^3)	(14) Total Perm. Fuel (ft^3) (5) + (6)	(15) Net Ballast (ft^3) (13) - (14)	(16) Net Ballast Wt. (LT) (15) ÷ 35	(17) Total Perm Fuel (LT) (14) ÷ 43	(18) Full Bal. Cond Fluid Wt (LT) (16) + (17)
Forebody	#1	333	16	317	9.06	0.37	9.43
	#2	321	13	308	8.80	0.30	9.10
	#3	321	13	308	8.80	0.30	9.10
	#4	279	12	267	7.63	0.28	7.91
	#5	279	12	267	7.63	0.28	7.91
Afterbody	#6	282	12	270	7.71	0.28	7.99
TOTALS		1815ft^3	78 ft^3	1737ft^3	49.63 LT.	1.81 LT	51.44LT

TANK CAPACITY DERIVATION

FIGURE 5-2
SH 3 of 3

SHIP - FULL LOAD CONDITION 'D'

	WT	KG	MOM
SHIP	140.29	6.24	876.07
B/F TANK (EMPTY)	22.20	-15.50	-344.10
STRUT	7.70	-6.18	-47.59
	170.19 L.T.	2.85	484.38 FT T

FOIL SYSTEM BUOYANCY	4.28	-12.00	51.36
TANK BUOYANCY	68.39	-15.50	-1060.05
STRUT BUOYANCY	1.23	-10.00	-12.30
	73.90	-13.81	-1020.99

DYNAMIC LIFT

W/EMPTY TANK		96.29 LT
W/FULL FUEL	(42.62T)	138.91
W/FULL BALLAST	(51.44T)	147.73

BUOYANCY/FUEL TANK-LIFT & BUOYANCY

FIGURE 5-3 SH 1

SHIP-MINIMUM OPERATING CONDITION 'B'

	WT	KG	MOM
SHIP	127.25	6.51'	828.81 FT, T.
B/F TANK (EMPTY)	22.20	-15.50'	- 344.10
STRUT	7.70	- 6.18'	- 47.59
	157.15 LT	2.78'	437.12 FT. T.

BUOYANCIES (FROM CONDITION 'D') + 73.90 L.T.

DYNAMIC LIFT

W/EMPTY TANK		83.25 L.T.
W/FULL FUEL	(42.62 L.T.)	125.87
W/FULL BALLAST	(51.44 LT)	134.69

FIGURE 5-3 SH 2

5.1 (Cont'd) Prior to the decision to utilize the diaphragm method of liquid separation, other bladder installations were examined and rejected as noted in Section 5.7. Also, the use of segregated tanks was investigated with the following conclusions, among others:

(a) The gross fuel capacity would have been reduced to approximately 23 tons.

(b) Fuel cells would have required a vent line, as well as fill and suction line.

(c) Ballast cells would have required that a fill and discharge system be developed, probably requiring additional lines between hull and tank.

(d) Buoyancy could have exceeded the limit dictated by stability.

(e) Free surface would have had an adverse effect on stability.

In light of the foregoing, which appeared to adversely affect cost and installation, it was decided to use the diaphragm method of separation.

5.2 Access - Access to the tank compartments is provided thru flush bolted plates on the tank side at each of the three mid-tank buoyancy spaces. From these buoyancy voids, manholes in the transverse bulkheads provide access to both the fuel and ballast cells above and below the diaphragm.

Access to the nose and tail cone is provided by physically removing the cones from the tank.

5.3 Loads - The primary loads for the analysis of the tank and attachment fittings were provided by DTNSRDC letter Reference 9, and as modified by Reference 23.

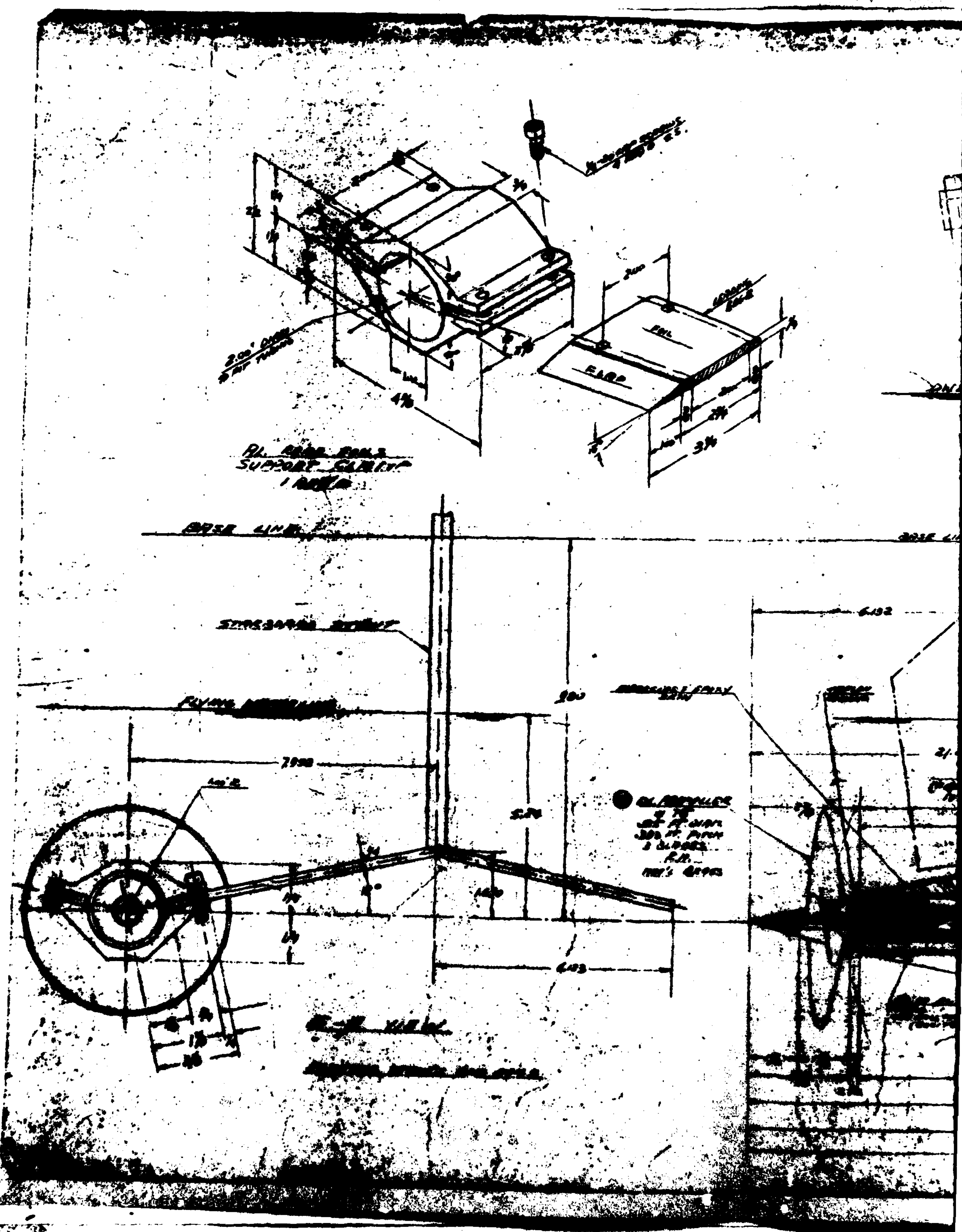
As noted in the references, the applied loads for the PCH-1 were derived from both model tests, and simulation runs. The model used was a 1/20 scale model of a tank attached to the hull of a PHM in a manner similar to that utilized in the M169 design. This model is described in Figure 5-4. The data obtained from the test runs was analyzed, Reference 22, and significant results converted to corresponding loads for the PCH. Further analytical work was performed by Grumman, Reference 25, to provide the loads used in the detail design phase.

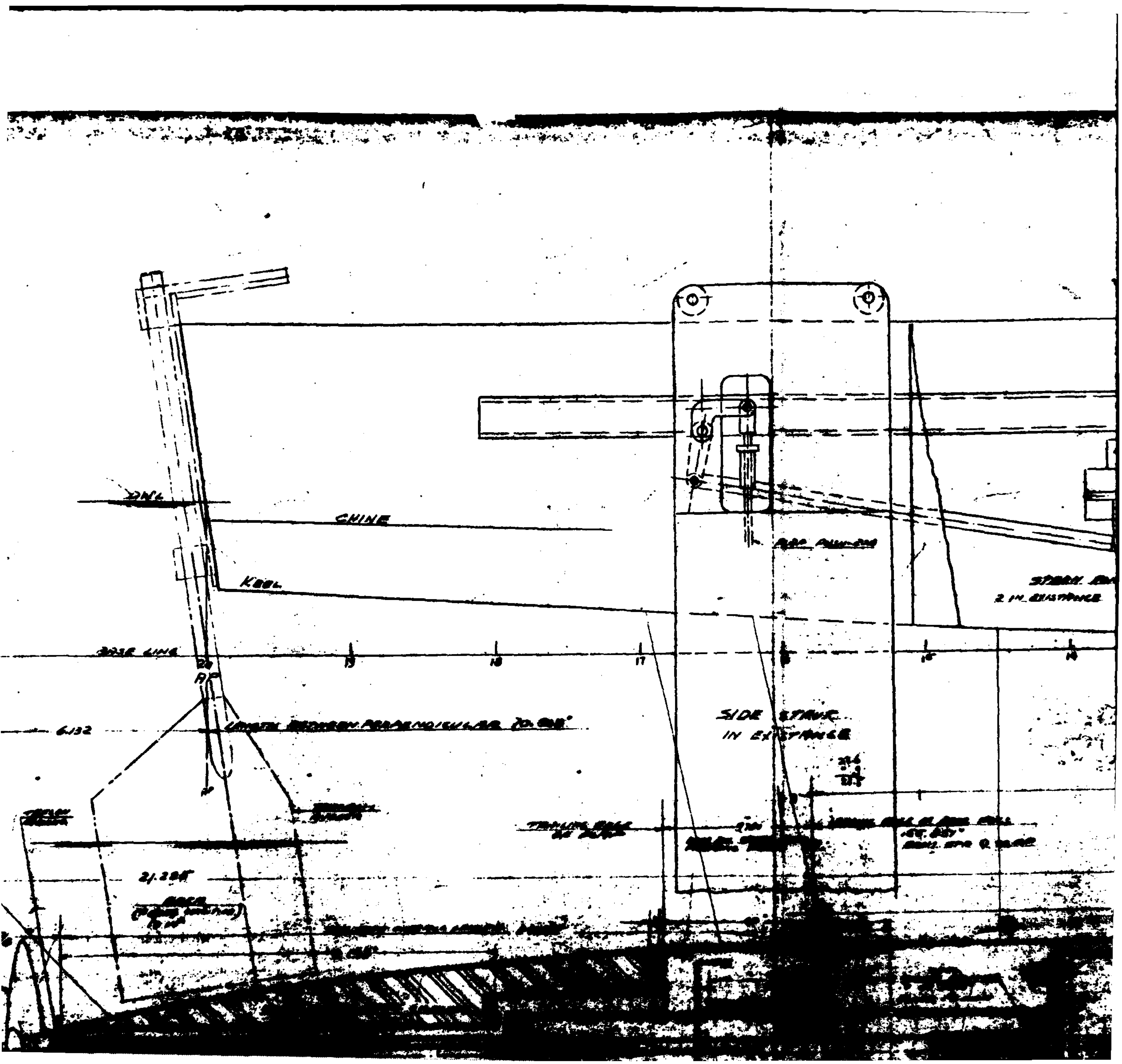
Design loads on the tank and attachment fittings are given in Ref. 25, and are the values recorded during the simulation runs noted therein. Maximum internal loads are developed by the sea water ram pressue at V_{max} of 40 knots, Section 6.1.1, and it is for these loads that the tank bulkheads are designed. The tank shell, subject to both internal and external loads, is, however, designed for the combined load which induces the highest stress level in the plating.

The aft foil/tank attachment fitting is capable of taking vertical and side loads only.

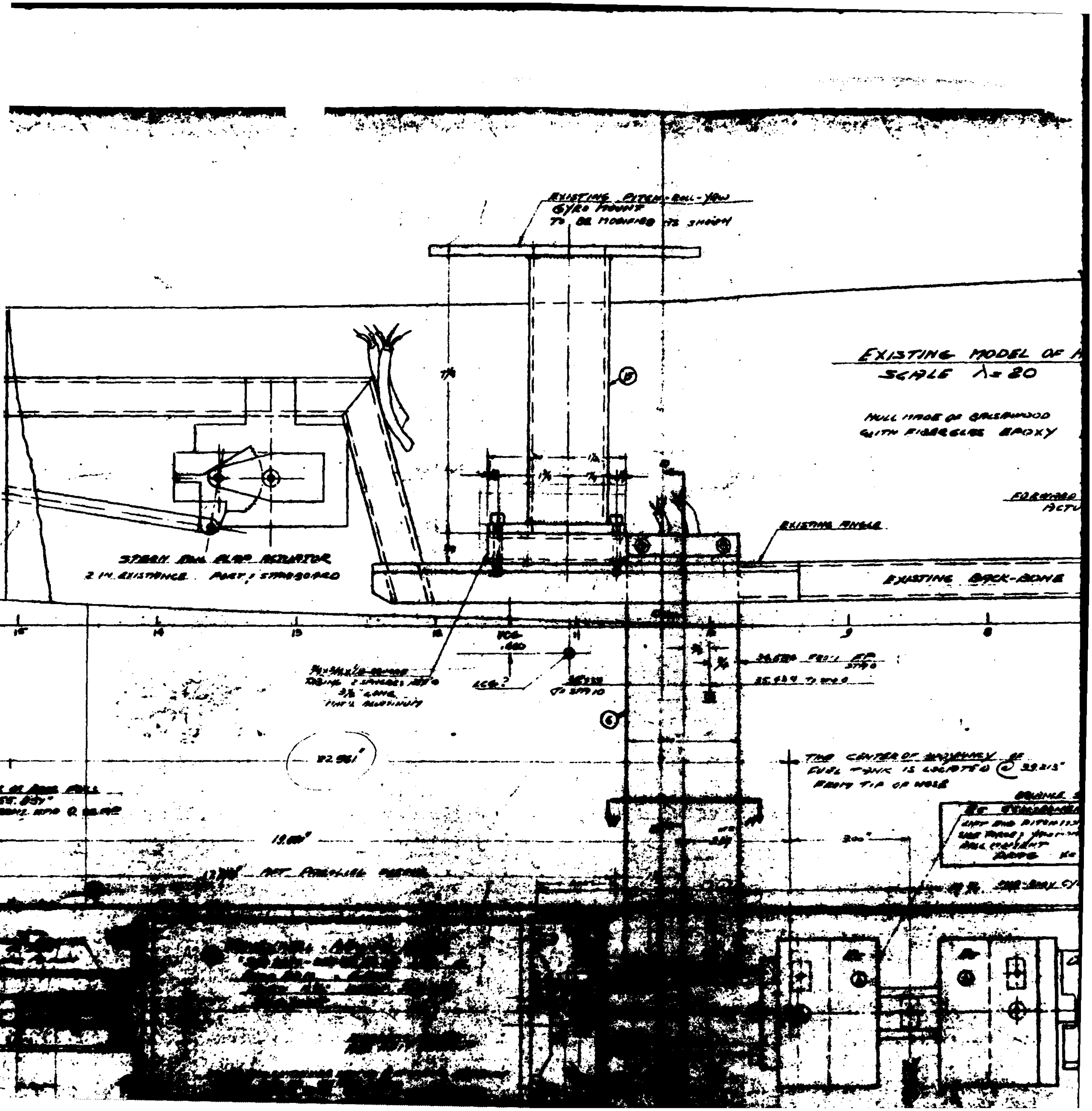
The existing aft struts were anlayzed by the moment distribution method for the combined effects of the lift load plus the side load of the buoyancy/fuel tank. In this condition, the maximum stress occurs in the foil at the intersection with the strut and is in the range of 66,000 psi. As the foil in this area is fabricated of HY 130 steel, a satisfactory factor of safety of 2.89 exists in this conditon.

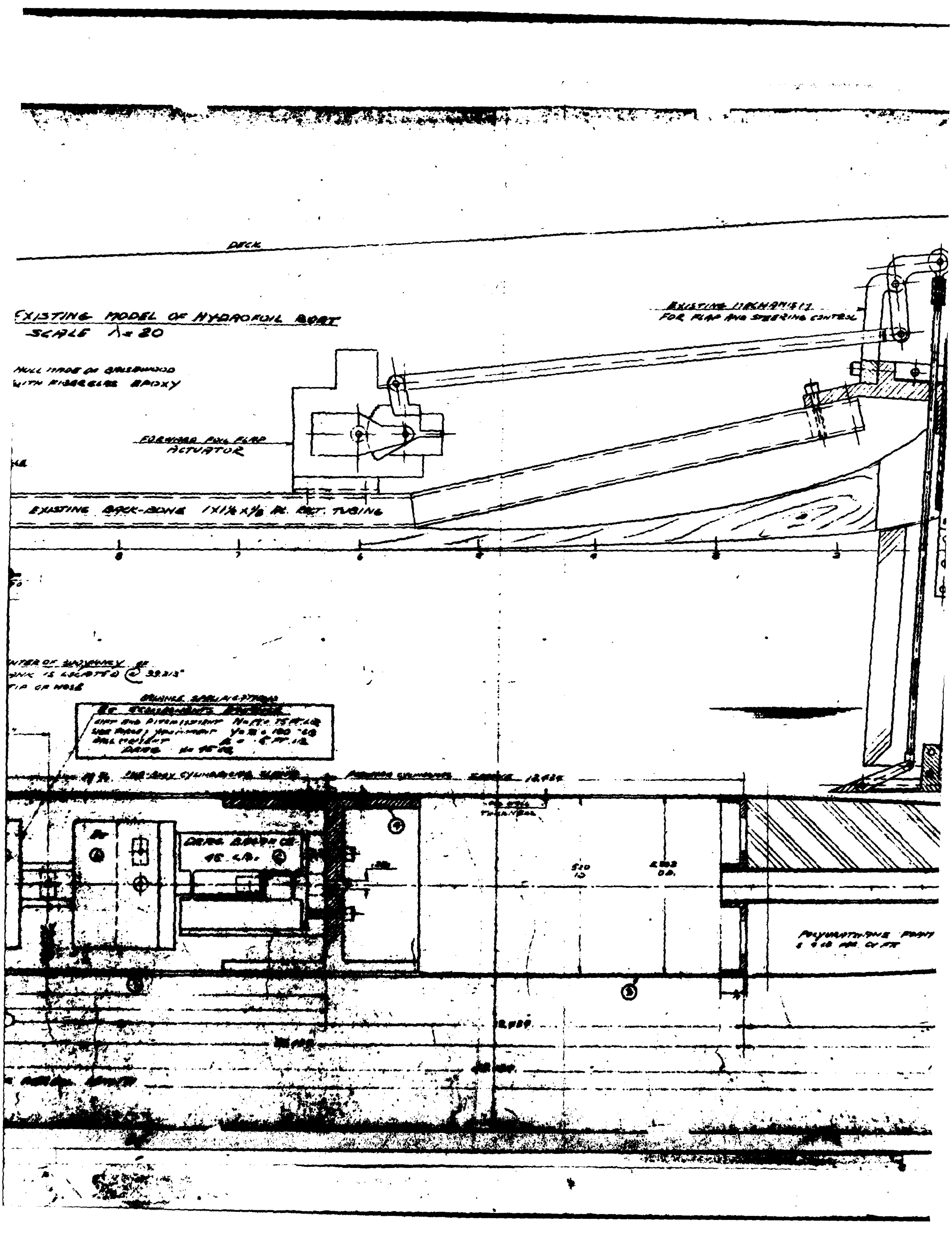
5.4 Material - The material selected for the structural portions of the tank is HY-80 or equivalent steel. This material has excellent fabrication properties and is currently readily available. To accomodate the loads with minimum weight, the strut is proposed to be fabricated from HY 100 steel. Properties from Reference 7 are as follows:

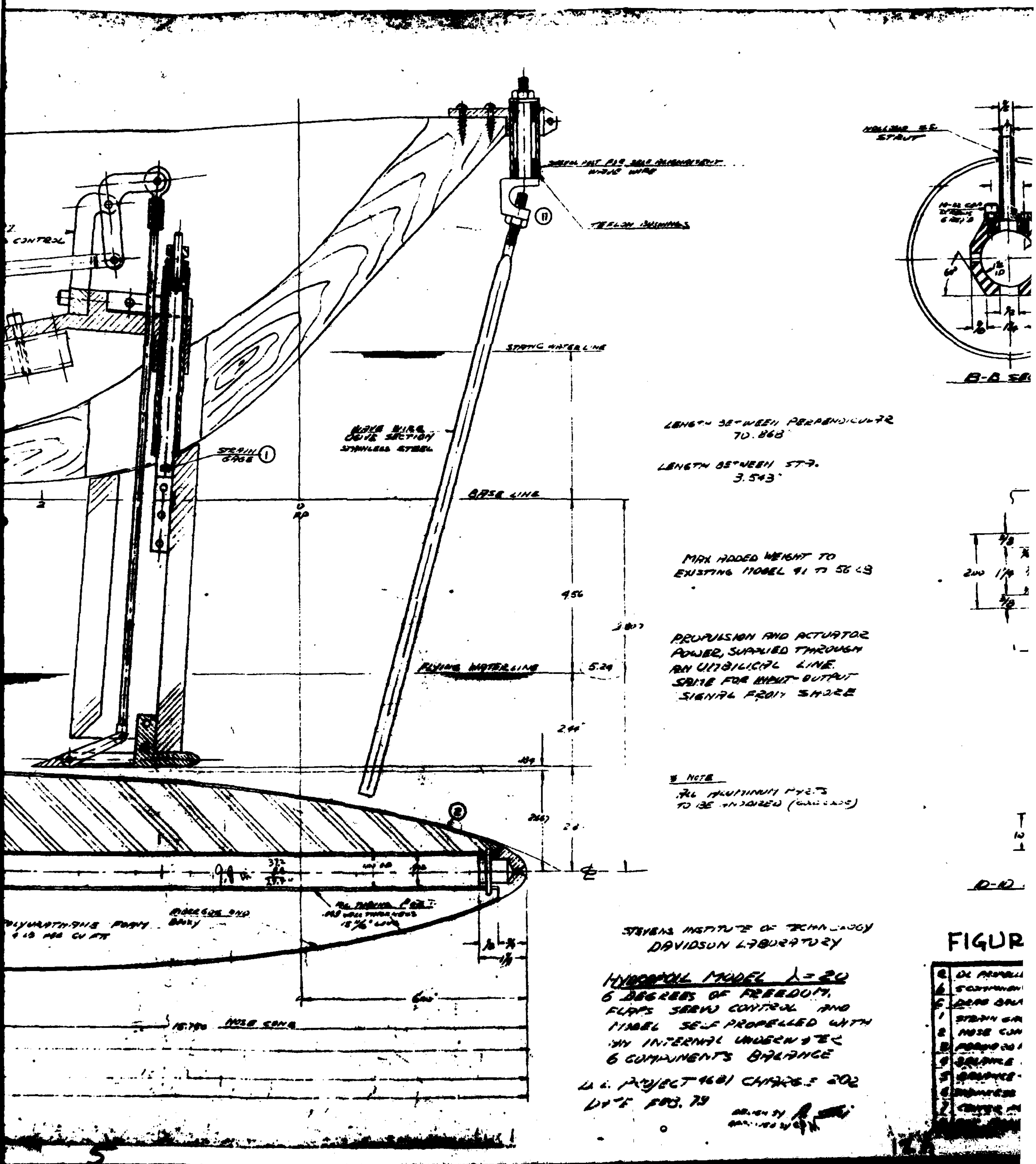

FOIL
FLAP
BASE LINE
STARBOARD STRUT
FLYING WATERLINE
7.938
6.132
6.103
SUPPORT



DWL
CHINE
KEEL
BASE LINE
20
19
18
17
16
15
14
AP
6.132
SIDE STRUT
IN EXISTANCE
21.295"
2 IN. EXISTANCE


EXISTING PITCH-ROLL-YAW
GYRO MOUNT
TO BE MODIFIED AS SHOWN
EXISTING MODEL OF
SCALE λ= 20
HULL MADE OF BALSAWOOD
WITH FIBERGLAS EPOXY
STERN ROLL FLAP ACTUATOR
2 IN EXISTANCE PORT, STARBOARD
EXISTING ANGLE
EXISTING BACK-BONE
THE CENTER OF BOUYANCY OF
FUEL TANK IS LOCATED @ 39.213"
FROM TIP OF NOSE
22.561"
19.00"


DECK
EXISTING MODEL OF HYDROFOIL BOAT
SCALE 1=20
HULL MADE OF BALSAWOOD
WITH FIBERGLAS EPOXY
EXISTING MECHANISM
FOR FLAP AND STEERING CONTROL
FORWARD FOIL FLAP
ACTUATOR
EXISTING BACK-BONE
POLYURETHANE FOAM



TEFLON BUSHINGS
STATIC WATERLINE
WAVE WIRE
OGIVE SECTION
STAINLESS STEEL
STRAIN GAGE
BASE LINE
FLYING WATERLINE
4.56
5.24
2.44
NOSE CONE
15.780
B-B SEC
D-D
LENGTH BETWEEN PERPENDICULARS
70.868
LENGTH BETWEEN STA.
3.543
MAX ADDED WEIGHT TO
EXISTING MODEL 41 TO 56 LB
PROPULSION AND ACTUATOR
POWER, SUPPLIED THROUGH
AN UMBILICAL LINE.
SAME FOR INPUT-OUTPUT
SIGNAL FROM SHORE
NOTE
ALL ALUMINUM PARTS
TO BE ANODIZED
STEVENS INSTITUTE OF TECHNOLOGY
DAVIDSON LABORATORY
HYDROFOIL MODEL λ=20
6 DEGREES OF FREEDOM,
FLAPS SERVO CONTROL AND
MODEL SELF PROPELLED WITH
AN INTERNAL UNDERWATER
6 COMPONENTS BALANCE
D.L. PROJECT 4681 CHARGE 202
DATE FEB. 79
FIGUR

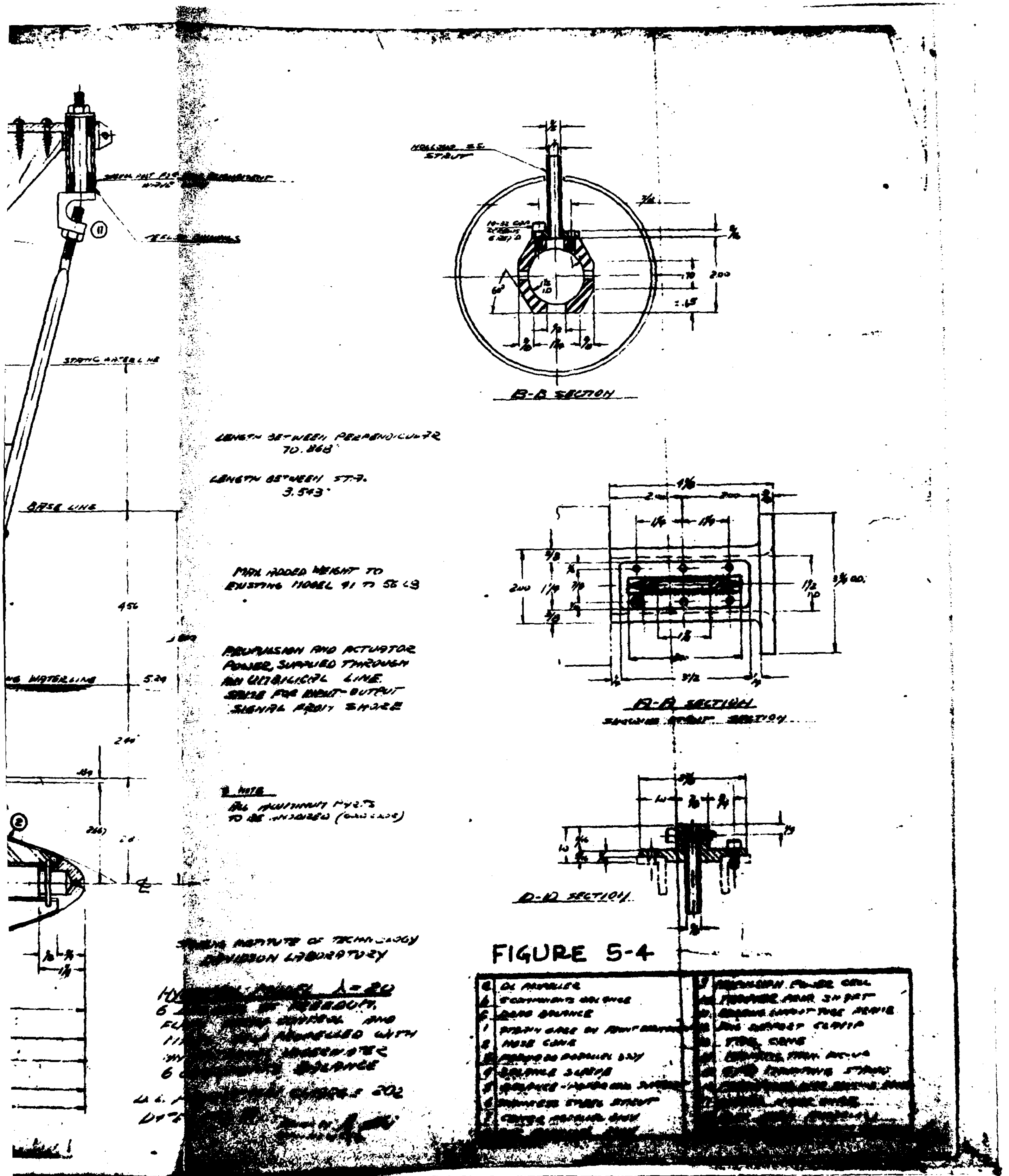

HOLLOW S.S. STRUT
B-B SECTION
LENGTH BETWEEN PERPENDICULAR
70.868
3.543
MAX ADDED WEIGHT TO EXISTING MODEL
PROPULSION AND ACTUATOR POWER SUPPLIED THROUGH AN UMBILICAL LINE. SAME FOR INPUT-OUTPUT SIGNAL FROM SHORE
NOTE
ALL ALUMINUM PARTS TO BE ANODIZED
A-A SECTION
D-D SECTION
BASE LINE
WATERLINE
DAVIDSON LABORATORY

FIGURE 5-4

5.4 (Cont'd)

	HY 80	HY 100
Tensile Strength - Ultimate	104,600 psi	116,400 psi
Tensile Strength - Yield 0.2%	87,650 psi	101,200 psi
Elongation in 2 inches	28%	23%
Fatigue Strength N = 10^5 (Sea Water- Smooth Specimen) R = -1.0	49,400 psi	50,800 psi

5.5 Structural Arrangement - The structural arrangement of the buoyancy/fuel tank is shown on Figure 5-1. The tank shell is a body of revolution six feet in diameter, stiffened by transverse bulkheads spaced a maximum of 12' -1" feet apart to form the fuel/ballast compartments.

Calculations for the derivation of scantlings for the tank are contained in Reference 28.

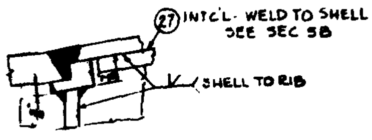
The nose cone is a separate unit of molded fiberglass bolted directly to the tank shell.

The afterbody is fabricated with a removable section to facilitate assembly. This section, of molded fiber-glass, is mounted in a manner similar to the nose cone.

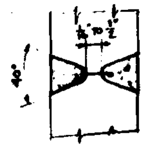
Except for the mechanical manhole and cone fasteners, the entire tank is to be welded in accordance with Specification MIL-STD-1688(SH). Weld joint design is to be in accordance with MIL-STD-0022C(SH).

be in accordance with MIL-STD-0022C(SH).

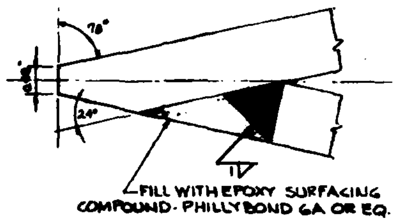
5.6 The B/F tank is permanently attached to, and supported by a single center line strut, Figure 5-5. It is fabricated from HY100 steel with a constant NACA16-012 section up to the knuckle from whence it tapers to a NACA-16-010 section at the hull interface. Primary load beams are carried thru the tank shell and welded to bulkheads.



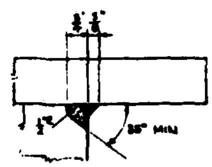
DET. 8D
SCALE: 6"=1'-0"



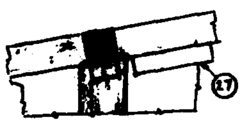
DET. 8C
L.E. & T.E. BUTT
SCALE: 6"=1'-0"



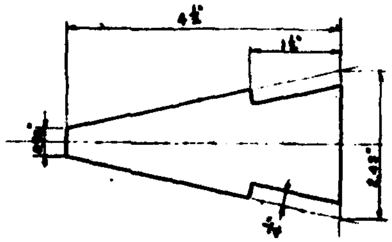
DET. 9C
TRAILING EDGE IN WAY OF 1" RT
SCALE: FULL



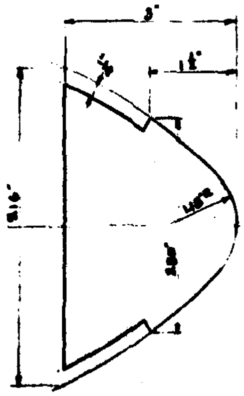
DET. 8B
L.E. & T.E. WELD TO FLANGE
SCALE: 6"=1'-0"



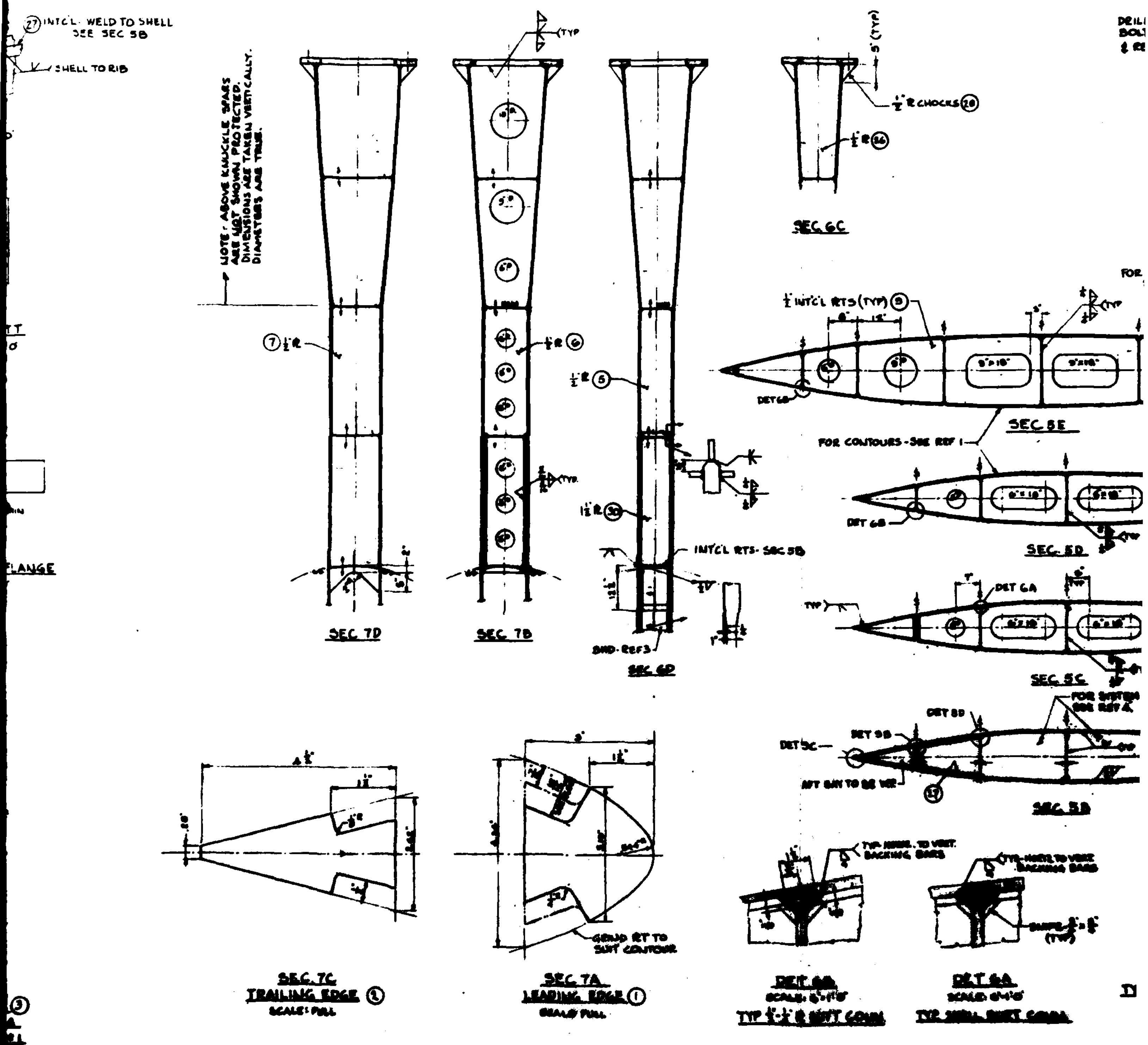
DET. 9B
SCALE: 6"=1'-0"



SEC. 9A
TOP OF TRAILING EDGE (4)
TAPER UNIFORMLY TO SEC. 7C
AT BOTTOM TO MATCH [illegible]
SCALE: FULL

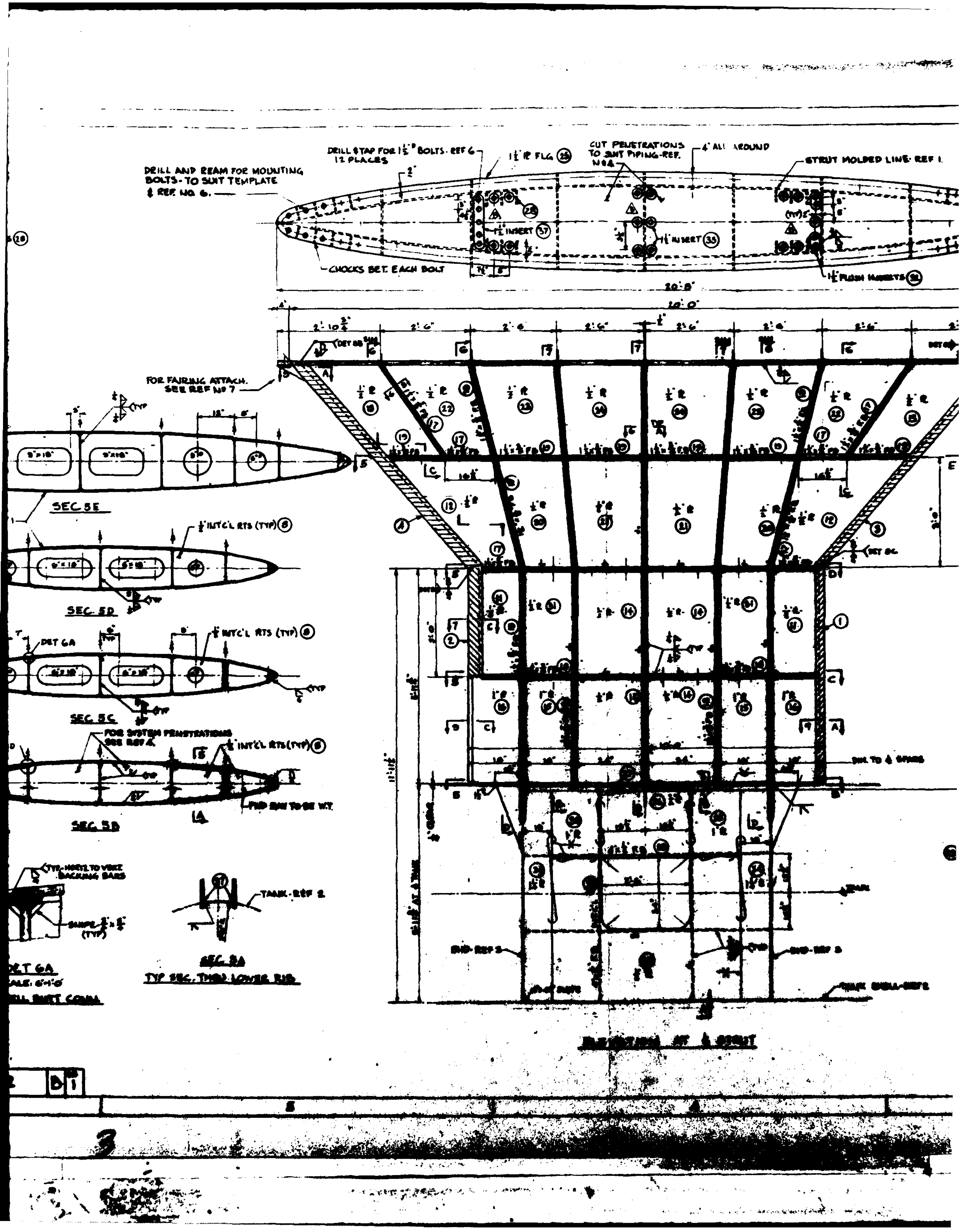


SEC. 8A
TOP OF LEADING EDGE (3)
TAPER UNIFORMLY TO SEC. 7A
AT BOTTOM TO MATCH [illegible]
SCALE: FULL

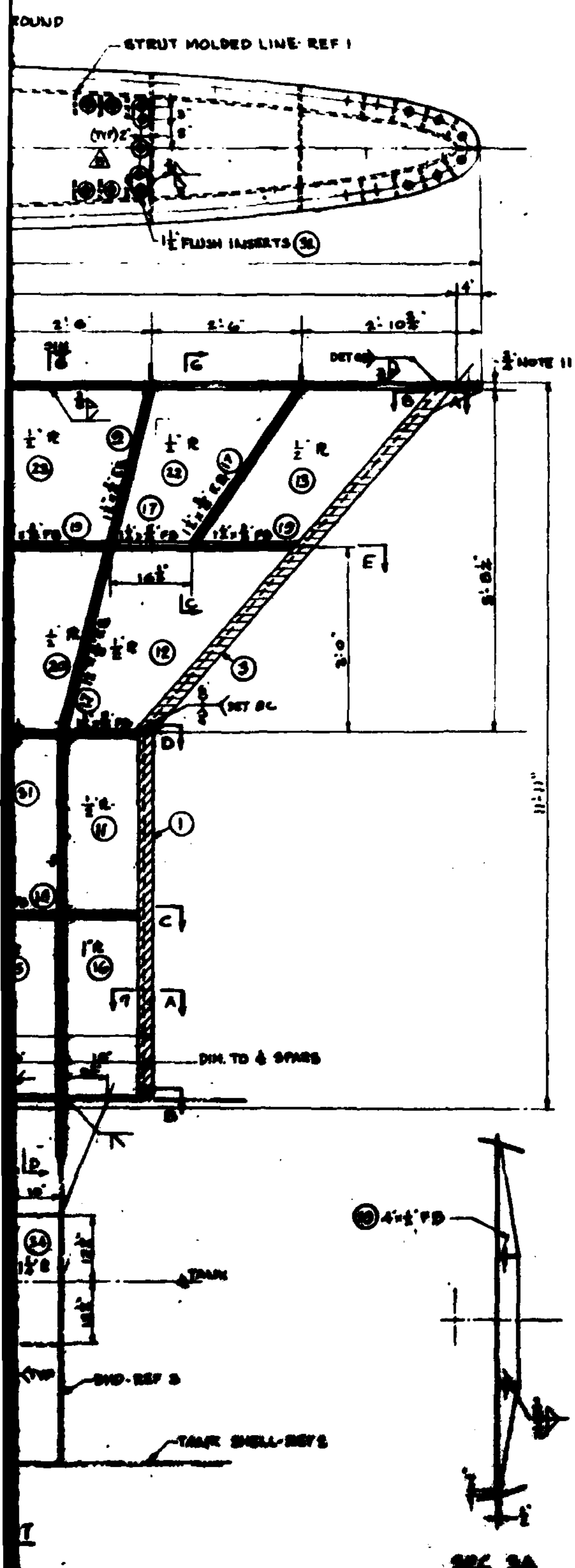


27 INTC'L. WELD TO SHELL SEE SEC 5B
SHELL TO RIB
NOTE: ABOVE KNUCKLE SPARS ARE NOT SHOWN PROTECTED. DIMENSIONS ARE TAKEN VERTICALLY. DIAMETERS ARE TRUE.
SEC 7D
SEC 7B
SEC 6D
SEC 6C
1/2" R CHOCKS 28
INT'C'L RTS - SEC 5B
FOR CONTOURS - SEE REF 1
SEC 5E
SEC 5D
SEC 5C
SEC 5B
DET 6B
DET 6A
DET 5C
SEC 7C
TRAILING EDGE 2
SCALE: FULL
SEC 7A
LEADING EDGE 1
SCALE: FULL
GRIND RT TO SUIT CONTOUR
DET 6B
DET 6A
FLANGE

7



DRILL & TAP FOR 1½" BOLTS - REF 6 - 12 PLACES
DRILL AND REAM FOR MOUNTING BOLTS - TO SUIT TEMPLATE & REF. NO. 6.
CUT PENETRATIONS TO SUIT PIPING - REF. NO. 4
4" ALL AROUND
STRUT MOLDED LINE - REF 1
CHOCKS BET. EACH BOLT
FLUSH INSERTS
20'-8"
20'-0"
FOR FAIRING ATTACH. SEE REF NO 7
SEC 5E
½" INTC'L RTS (TYP)
SEC 5D
DET 6A
SEC 5C
FOR SYSTEM PENETRATIONS SEE REF 4
SEC 5B
TANK - REF 2
SEC 8A
TYP SEC. THRU LOWER RIB
DET 6A



GENERAL NOTES

(A) 1. FABRICATION, WELDING, & INSPECTION TO BE IN ACCORDANCE WITH MIL-STD-1688 (SH)

2. WELD JOINT DESIGN TO BE IN ACCORDANCE WITH MIL STD 0022C(SH).

(A) 3. WELDING PROCESSES & FILLER MATERIALS TO BE IN ACCORDANCE WITH TABLE VI OF MIL-STD-1688(SH). CARE SHOULD BE EXERCISED TO PREVENT THE FORMATION OF WELD OCCLUSIONS

4. STRUT TO BE TESTED IN ACCORD. WITH REF 5.

5. WELD INSPECTION TO BE AS FOLLOWS:
   a) VISUAL INSPECTION - ALL WELDS
   b) AIR AND SOAP SOLUTION - ALL ACCESSIBLE EXTERNAL WELDS
   c) MAGNETIC PARTICLE INSPECTION - 20% OF ALL WELDS
   d) RADIOGRAPHIC INSPECTION - VERTICAL BUTT WELDS

6. TEMPLATE PLATE SIZE AND SHAPE FROM WORK & REF Nº 1.

7. FINISH STRUT SURFACES AS FOLLOWS:
   a) INTERIOR - MIL-C-16173 GR 1, SLOSH & DRAIN
   b) EXTERIOR - DEXTER CORP (MIDLAND DIV) LAMINAR X500 SYSTEM - SEE GN Nº 9
   c) PARTS WITHIN W/F TANK - DOD-P-23236 CL 3

8. CONTOURS TO BE FAIR TO ± 3/16" BETWEEN RIBS & SPARS

9. FOR FINISHING OF MOUNTING FLG SEE REF Nº 6

10. ALL EXTERIOR WELDS TO BE GROUND FLUSH.

11. TOP FLG TO BE MACHINED SQUARE - 3/4" MIN THICKNESS

RESERVATIONS

~~1. ATTACHMENTS FOR FAIRING~~

REFERENCES			
NO.	TITLE	NAVSEA DWG. NO.	GAC DWG. NO.
1	LINES & OFFSETS - STRUT	[illegible]	[illegible]
2	W/F TANK - SHELL	-5584940	[illegible]
3	W/F TANK - BULKHEADS	-5584941	[illegible]
4	STRUT PIPING	[illegible]	[illegible]
5	TEST MEMORANDA	[illegible]	-84101
6	STRUT INSTALLATION	[illegible]	[illegible]
7	STRUT JOINT FAIRING	[illegible]	-11402

ITEM NO
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LIST OF MATERIALS

ITEM NO	QTY REQD	NOMENCLATURE: TYPE NUMBER	NOMENCLATURE: ITEM NAME	DRAWING OR SPEC. NO.	REMARKS
1	1	STEEL	LEADING EDGE	ASTM A242 OR A441	4½" x 3" x 6'-6"
2	1		TRAILING EDGE		4½" x 2½" x 5'-3"
3	1		LEADING EDGE		6" x 3" x 8'-0"
4	1	STEEL	TRAILING EDGE	ASTM A242 OR A441	5" x 4" x 8'-0"
5	2	STEEL HY100	SPAR	MIL-S-16216	½" x 28" x 8'-0"
6	2				½" x 28" x 12'-9"
7	1		SPAR		½" x 24" x 15'-6"
8	3		RIB INTERCOSTALS		½" x 16" x 18'-0" TO CUT
9	1		RIB INTERCOSTALS		½" x 18" x 18'-6" TO CUT
10	2		TORQUE BOX		½" x 6'-0" x 4'-3"
11	4		SIDE RT		1" x 18" x 3'-3"
12	4				½" x 2'-3" x [illegible]
13	4				½" x 24" x 4'-9"
14	8				½" x 2'-2" x 8'-8"
15	4				1" x 20" x 3'-3"
16	4		SIDE RT		1" x 18" x 3'-3"
17	40 FT		BACKING BAR		1½" x ⅜" F.B. TO CUT
18	28 FT				1½" x ⅜" F.B. TO CUT.
19	75 FT		BACKING BAR		1½" x ⅜" F.B. TO CUT
20	4		SIDE RT		½" x 26" x 3'-6"
21	4				½" x 2'-6" x 3'-9"
22	4				½" x 2'-3" x 4'-0"
23	4				½" x 2'-6" x 2'-9"
24	4		SIDE RT		½" x 2'-8" x 2'-9"
25	1		TOP FLANGE		½" x 3'-0" x 20'-8" NOTE 11
26	2		SPAR		½" x 15" x 2'-9"
27	1	STEEL HY100	BACKING BAR		½" x ⅜" x 22'-0" TO CUT
28	192	STEEL HY80	CHOCKS		½" x 3½" x 9"
29	55 FT	STEEL HY100	STIFFENERS		4" x ½" F.B. TO CUT
30	2		SPAR		1½" x 9" x 6'-2"
31	4		SIDE RT		½" x 20" x 3'-3"
32	2		INSERT		1½" x 3" x 6"
33	15		INSERT		1½" x 3"
34	4		TORQUE BOX		1½" x 24" x 6'-3"
35	4				1" x 18" x 24"
36	2	STEEL HY100	TORQUE BOX	MIL-S-16216	½" x 24" x 2'-6"
37	1	STEEL HY100	INSERT	MIL-S-16216	1½" x 3" x 19"
38					

B

B

B

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED
[illegible]	A	[illegible]	[illegible]	[illegible]
[illegible]	B	[illegible]	[illegible]	[illegible]

FIGURE 5-5

5584542 | B | T

5.7 Support and Detachment - The method of supporting and detaching the tank consists of bolting two mating flanges, one on the B/F tank strut and the other on the hull reinforcement.

5.7.1 Forward Strut - The forward strut, which is steerable, will have no connection whatsoever to the new buoyancy/fuel tank.

5.7.2 Aft Foil - The attachment of the tank to the existing aft foil is designed to take side and vertical loads only. The fitting consists of a tapered foil male section welded to the underside of the foil which mates loosely with its female counterpart on the top of the B/F tank afterbody.

5.7.3 Added Rudder, Aft - Additional rudder and horizontal stabilizers are to be installed on the aft end of the B/F tank as shown on Figures 5-1 and 8-1.

5.7.4 Installation - Installation of the tank to the craft may be accomplished with the craft on high stands, or in drydock. Inasmuch as the existing high stands must be modified, or new one provided in order to make the initial fit and installation, it is believed that they could also be utilized for detachment purposes.

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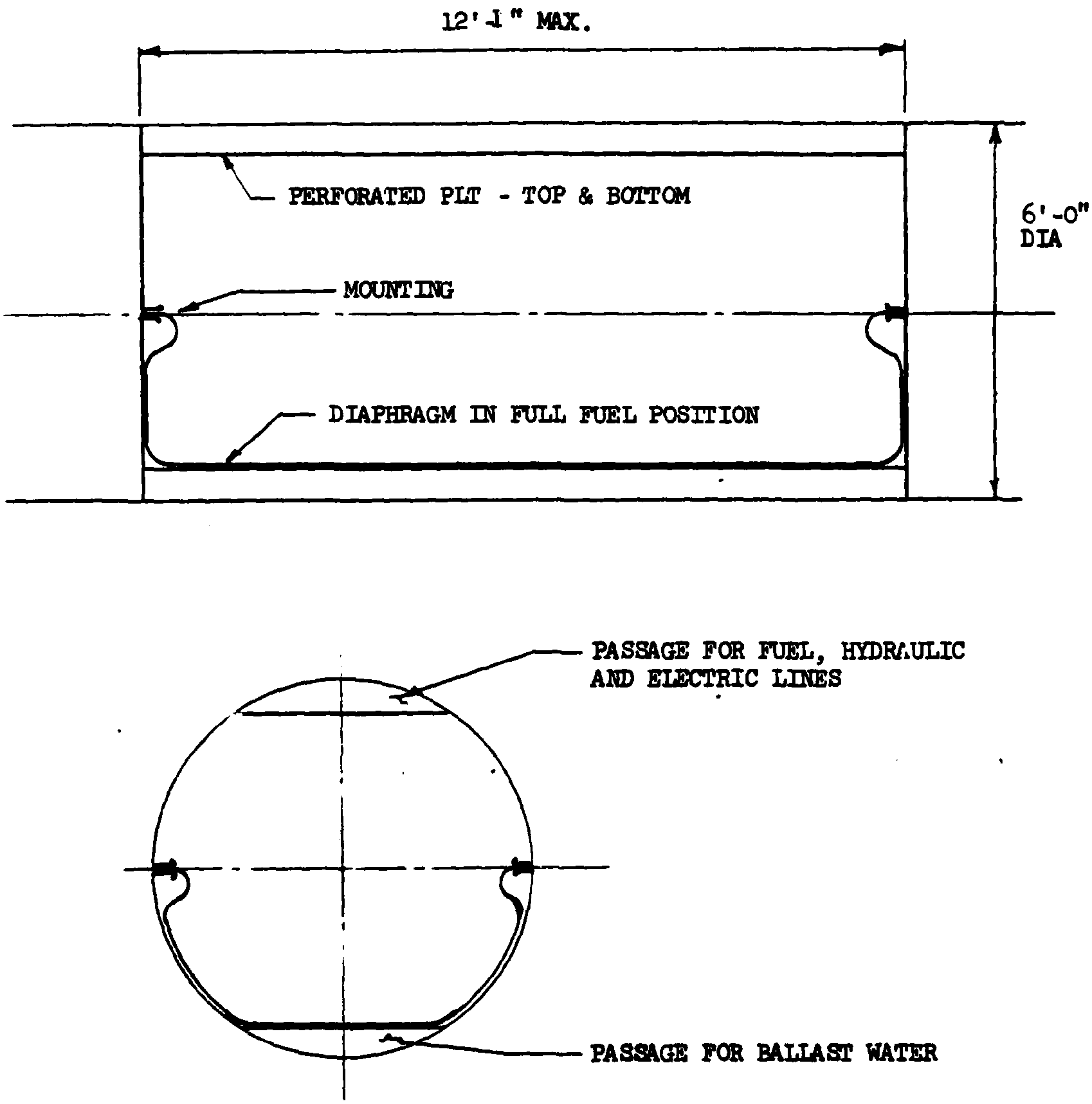
5.7.4 (Cont'd) By retracting the struts, added clearance will be provided for installing or removing the tank from beneath the hull.

5.8 Diaphragms - Each fuel/ballastcompartment is fitted with a horizontal flexible diaphragm at approximately the mid-point of the compartment. An oil-tight seal is provided around the periphery to prevent contamination of the fuel by the sea water ballast by clamping the diaphragm between two flat bars, one of which is welded to the tank structure. During operation, the diaphragm is pressurized on one side by either fuel or sea water, and the flexibility of the diaphragm displaces the liquid on the opposite side. Figure 5-6 depicts the typical arrangement of the diaphragm. The diaphragm material is non-self-sealing, fabricated of nylon reinforced nitrile rubber composition, in general accordance with Specification MIL-T-6396.

Prior to the selection of the diaphragm method of segregating liquids within the cells, alternate methods had been investigated and discarded as being more complicated or expensive. These would be the use of complete bladders within the cells, either with or without diaphragms. In the first instance, fuel would be contained in the



NOTES

1. DIAPHRAGMS TO BE RESISTANT TO DIESEL OIL, JP-5, AND SEA WATER.
2. DIAPHRAGMS TO BE NYLON REINFORCED NEOPRENE OR EQ.
3. MAX PRESSURE ON DIAPHRAGMS TO BE 40 PSI FROM BALLAST WATER RAM PRESSURE.
4. DIAPHRAGMS TO BE SUITABLY REINFORCED AT MOUNTING & FOLD POINTS.

TYPICAL DIAPHRAGM INSTALLATION

FIGURE 5-6

5.8 (Cont'd) upper half and sea water ballast in the lower. This would have, however, required pipe connection inserts in the bladder, and would have created inaccessible voids between the tank shell and the bladder.

In the second case, fuel would be contained within the bladder and ballast water outside. Consultation with potential fabricators confirmed that, due to the amount of bladder material to be folded, the quantity of unusable fuel contained in the folds would be increased over that anticipated with only the diaphragm.

SECTION 6

FLUID SYSTEMS

6.0 Fluid Systems Description - The modifications to the existing fluid systems to satisfy the requirements of the buoyancy/fuel tank have been kept to a minimum. Systems which would be affected are:

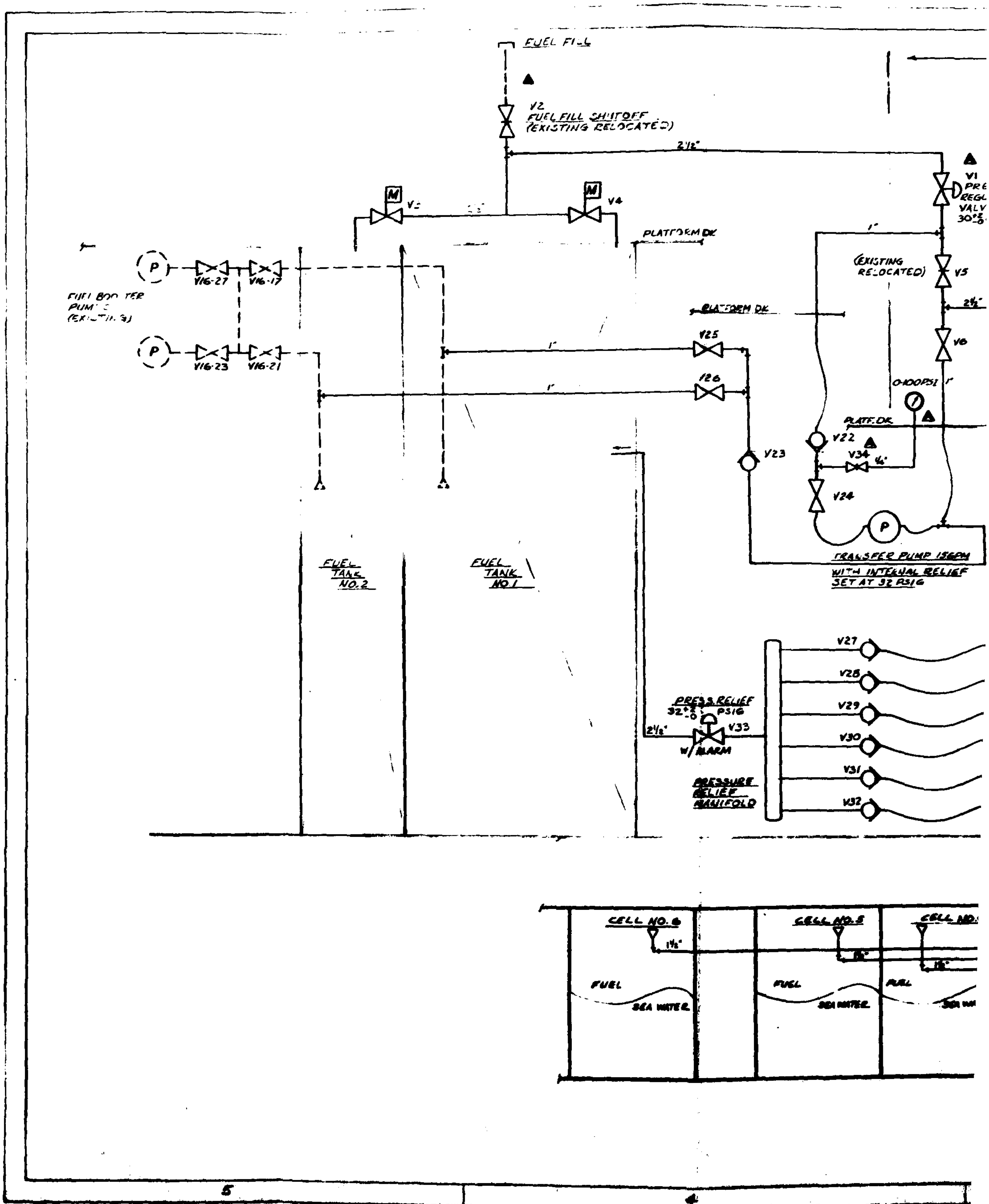
Fuel System	Section 6.1
Ballast System	Section 6.2
Compressed Air System	Section 6.3
Hydraulic System	Section 6.4

The initial charge of sea water ballast is obtained by launching the craft, which must be properly controlled to preclude developing an unstable condition. The static head of water, approximately 9.0 psi, entering through intakes in the nose and tail cones, will force the diaphragms up, expelling the air trapped in the ballast cavity out thru the small vent holes in the tank shell side. At the same time, the fuel fill lines must be opened to provide an atmospheric vent for the fuel cells. Conversely, fueling under pressure, in excess of the 9.0 psi sea water static head, will displace the ballast water and fill the fuel cells. Any air remaining in the fuel cells will be trapped at the top of the tank, and will presumably be expelled during the subsequent fuel transfer operation.

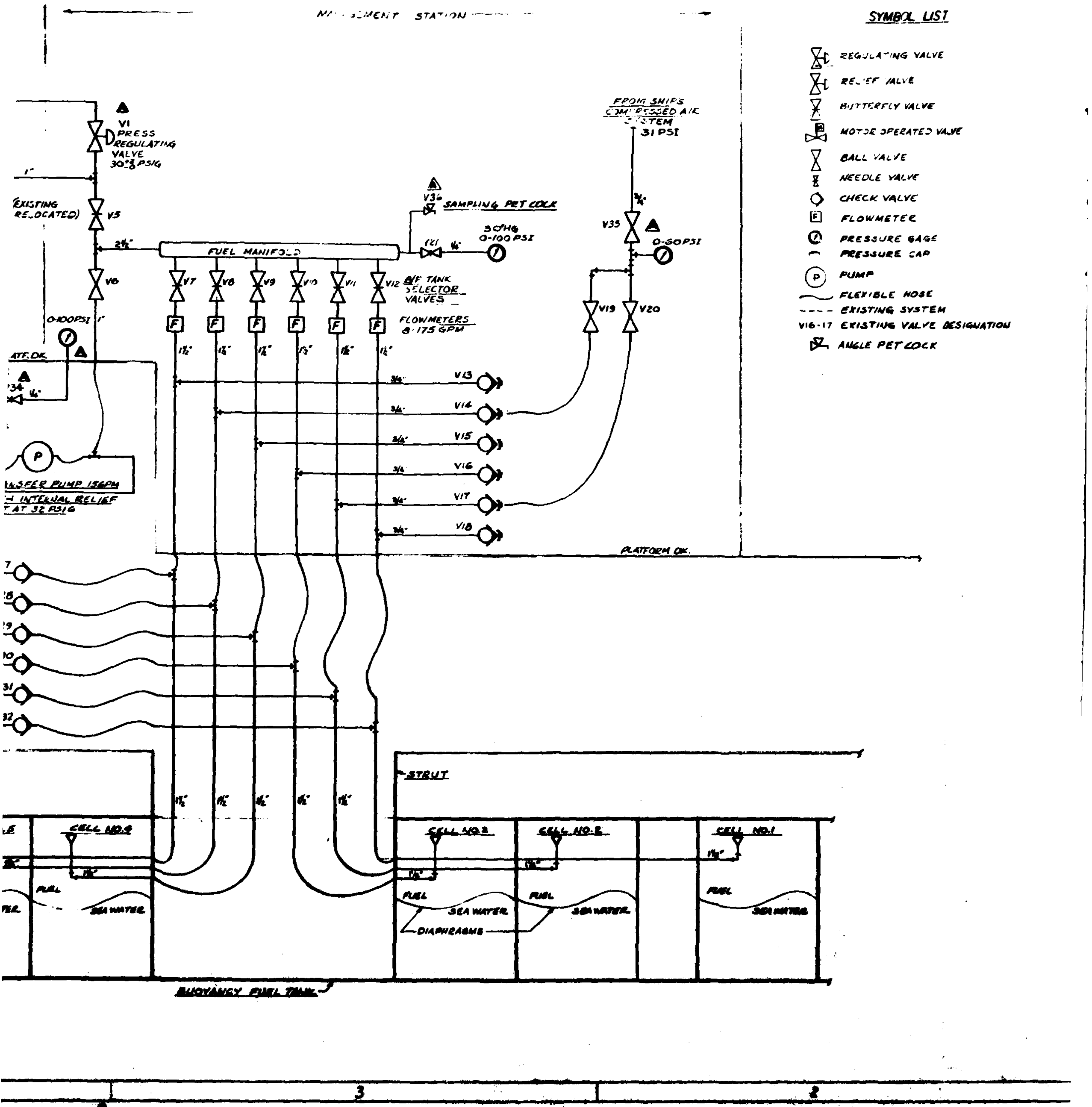
Pressure fueling should not exceed 40 psi to preclude rupturing the tank shell.

Fuel transfer from the fuel cells in the buoyancy/fuel tank to the hull tanks is accomplished thru selective valving and interconnecting piping within the hull. High level float switches installed in the hull tanks would control the flow from the submerged tank. A reverse transfer from the hull to the buoyancy/fuel tank may also be accomplished by utilizing a connection to the new 15 GPM transfer pump.

6.1 Fuel System - The fuel system proposed for the Extended Performance Hydrofoil Program PCH-1 demonstrator is schematically represented on Figure 6-1. Fueling of the six cells in the buoyancy/fuel tank is accomplished by using the existing ships fueling station. To preclude over-pressurizing the B/F tank cells, a regulator is installed in the fuel line.



FUEL FILL
V2
FUEL FILL SHUTOFF
(EXISTING RELOCATED)
2½"
V1
V4
PLATFORM DK
V16-27
V16-17
V16-23
V16-21
(EXISTING RELOCATED)
V5
V6
V25
V26
1"
0-100PSI
PLATF. DK
V22
V34
V23
V24
TRANSFER PUMP 15GPM
WITH INTERNAL RELIEF
SET AT 32 PSIG
FUEL TANK NO. 2
FUEL TANK NO. 1
V27
V28
V29
V30
V31
V32
PRESS. RELIEF
PSIG
V33
W/ ALARM
PRESSURE RELIEF MANIFOLD
CELL NO. 6
CELL NO. 5
FUEL
SEA WATER
5
4



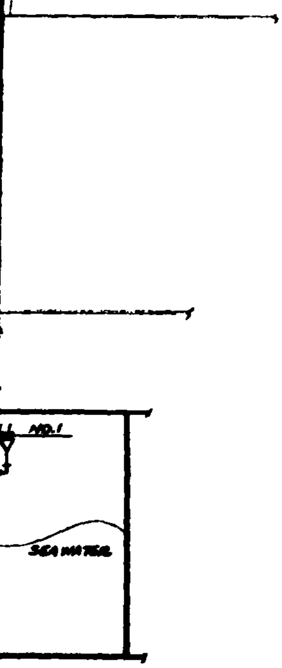
SYMBOL LIST
REGULATING VALVE
BUTTERFLY VALVE
MOTOR OPERATED VALVE
BALL VALVE
NEEDLE VALVE
CHECK VALVE
FLOWMETER
PRESSURE GAGE
PRESSURE CAP
PUMP
FLEXIBLE HOSE
EXISTING SYSTEM
V16-17 EXISTING VALVE DESIGNATION
ANGLE PET COCK
STATION
V1 PRESS REGULATING VALVE
(EXISTING RELOCATED) V5
FUEL MANIFOLD
V36 SAMPLING PET COCK
0-100 PSI
0-60PSI
31 PSI
V35
V6 V7 V8 V9 V10 V11 V12
FLOWMETERS 8-175 GPM
V13 V14 V15 V16 V17 V18
V19 V20
PLATFORM DK.
STRUT
CELL NO.4
CELL NO.3
CELL NO.2
CELL NO.1
FUEL
SEA WATER
DIAPHRAGMS
BUOYANCY FUEL TANK
3
2

SYMBOL LIST

- REGULATING VALVE
- RELIEF VALVE
- BUTTERFLY VALVE
- MOTOR OPERATED VALVE
- BALL VALVE
- NEEDLE VALVE
- CHECK VALVE
- FLOWMETER
- PRESSURE GAGE
- PRESSURE CAP
- PUMP
- FLEXIBLE HOSE
- ---- EXISTING SYSTEM
- V16-17 EXISTING VALVE DESIGNATION
- ANGLE PET COCK

REVISIONS

ZONE	LETTER	DESCRIPTION	DATE	APP'D.
2	A	ADDED VALVE V35 AND PRESS. INDICATOR TO COMP. AIR SYS.	7/29/81	[illegible]
3-4		RELOCATED VALVE V1, PRESS. REG., & WATER FILL LINE TO MANIFOLD IN MGMT STATION		
3-4		REVISED TO SHOW PUMP DISCHARGE PRESS. INDICATOR LOCATED IN MGMT STATION. - ADDED PET COCK V36		
2-4		REVISED TANK 1 THRU 6 IN B/F TANK TO CELL 1 THRU 6		



REFERENCES

NO.	TITLE	DRAWING NO. NAVSEA	DRAWING NO. GRUMMAN
1	MANAGEMENT STATION ARRGT.	802-[illegible]	[illegible]
2	FUEL SYS IN B/F TANK	802-[illegible]	[illegible]
3	SHIP MOD. FUEL SYS	[illegible]	[illegible]

FIGURE 6-1

2

6.1 (Cont'd) Transfer of the fuel from the B/F tank cells to the hull fuel tanks is accomplished by utilizing the ram pressure effect while foilborne, or a combination of static head and booster pump for hullborne transfer.

Each fuel cell is served by an independent fill/discharge line which are manifolded together in the management station area.

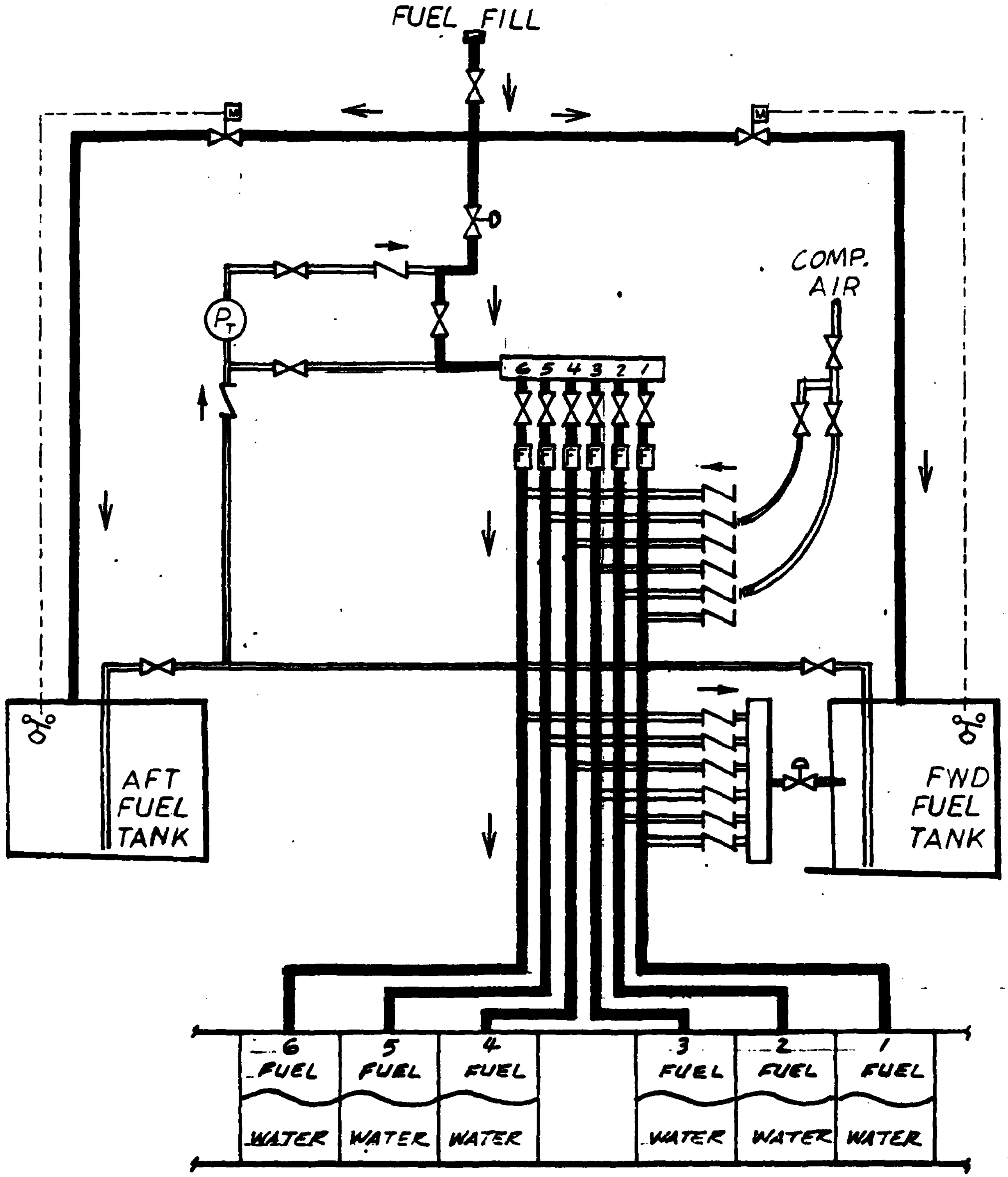
The primary additional fuel system components and functions are as follows:

- o Fuel Management manifold located in the hull to provide for selecting individual or any combination of fuel cell transfer functions.
- o Compressed air valves and flexible hoses to regulate air flow to each fuel cell for ballast blowing.
- o A relief valve in the fuel transfer system to prevent overpressurizing the fuel cells and diaphragms due to thermal or atmospheric expansion or other contingencies.
- o A transfer pump which may be used to fuel or defuel the B/F tank hullborne.
- o Fuel flowmeters which may be used to determine fuel flow rate and/or fuel quantity to and from each cell.
- o Two motor operated gate valves for selective fueling to the ship's system fuel tank No. 1 or tank No. 2. These two valves will also be controlled by high level float switches located in the ship's fuel tanks to prevent overfilling of the ship's fuel tanks.
- o Fuel pressure gage for monitoring the fuel transfer pressure.

Figures 6-2 through 6-5 depict the fuel management system in four modes, it is to be noted that a new 15 GPM transfer pump is incorporated into the modified system to permit hullborne fuel transfer without utilizing the existing fuel booster pumps.

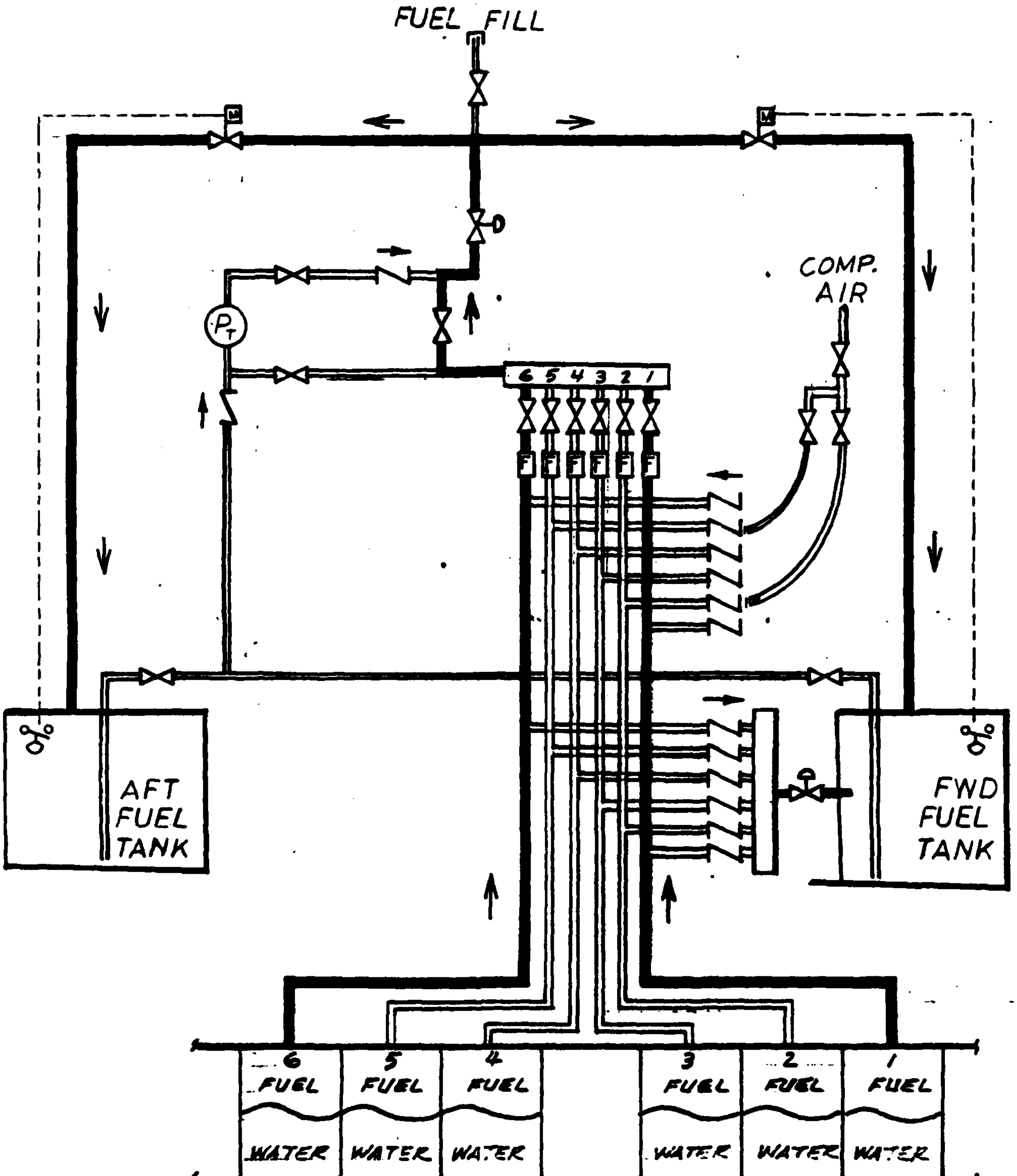
Suction inlets are located as close to the top of the cells as possible to minimize the amount of trapped air.

6.1.1 Fuel Transfer Analysis - Figures 6-6 and 6-7 include the current piping configuration and present dockside fueling rates as well as foilborne transfer. Cells 1 and 6 have been selected for this analysis as they have the longest piping runs and thus represent the worst case. For one or both cells as shown, the time to completely defuel at 40 knots would be approximately 30 minutes. Although the remaining tanks have shorter piping runs and thus less resistance they also have higher capacities



REFUELING ALL TANKS

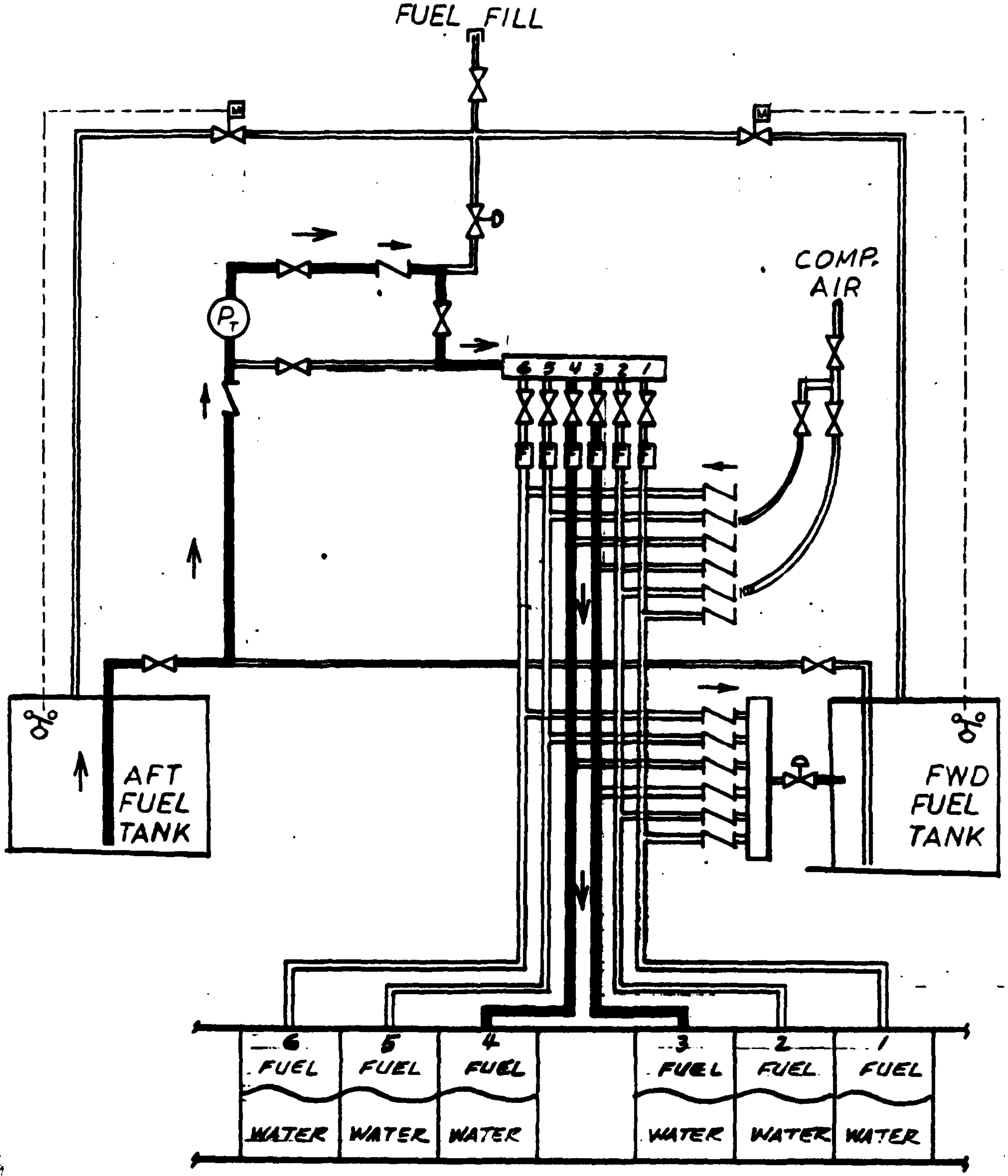
Figure 6-2



FOILBORNE FUEL TRANSFER

FROM B/F TANK CELLS 1 & 6 TO HULL TANKS

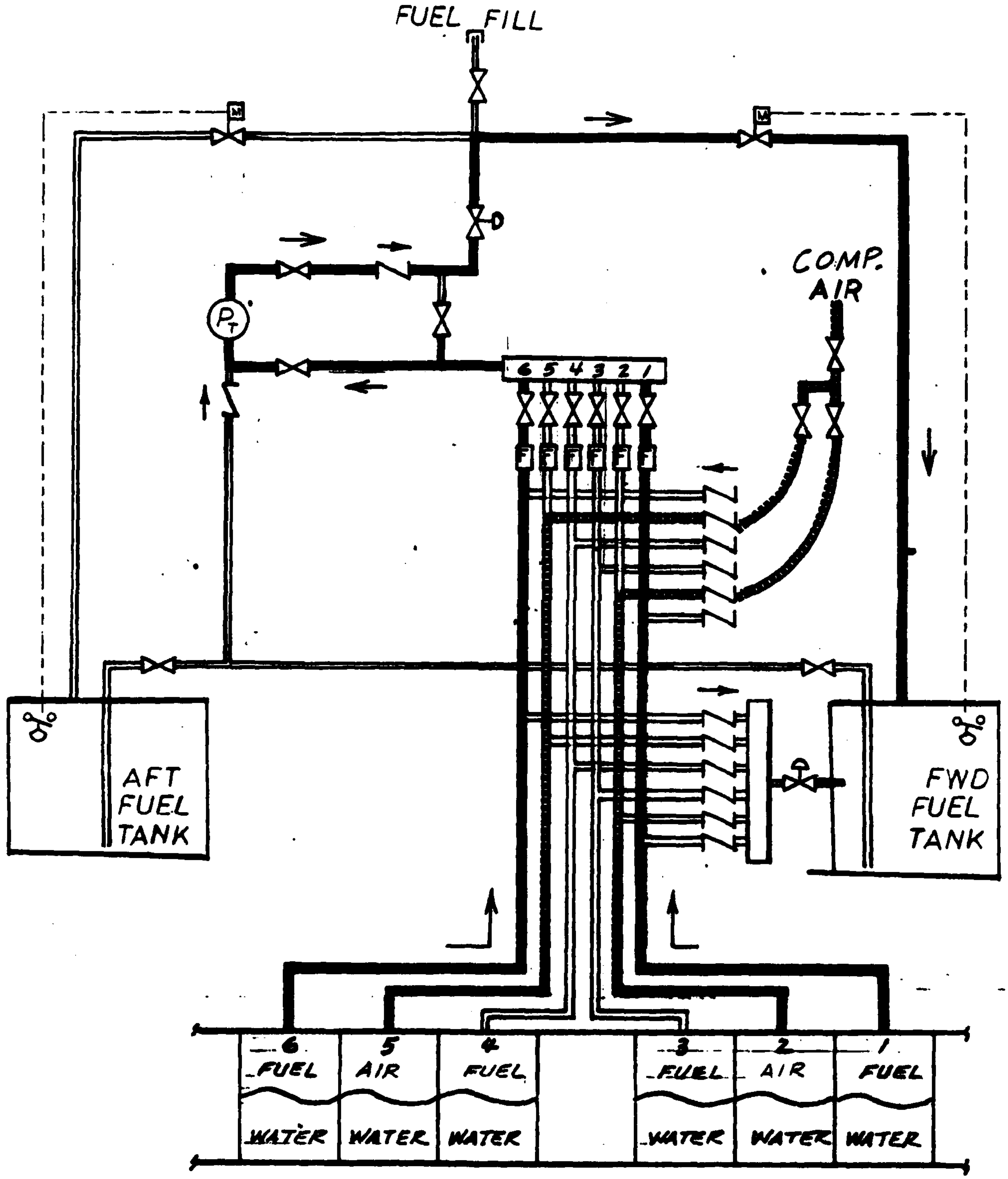
Figure 6-3



HULLBORNE FUEL TRANSFER

FROM HULL AFT TANK TO B/F TANK CELLS 3 & 4

Figure 6-4

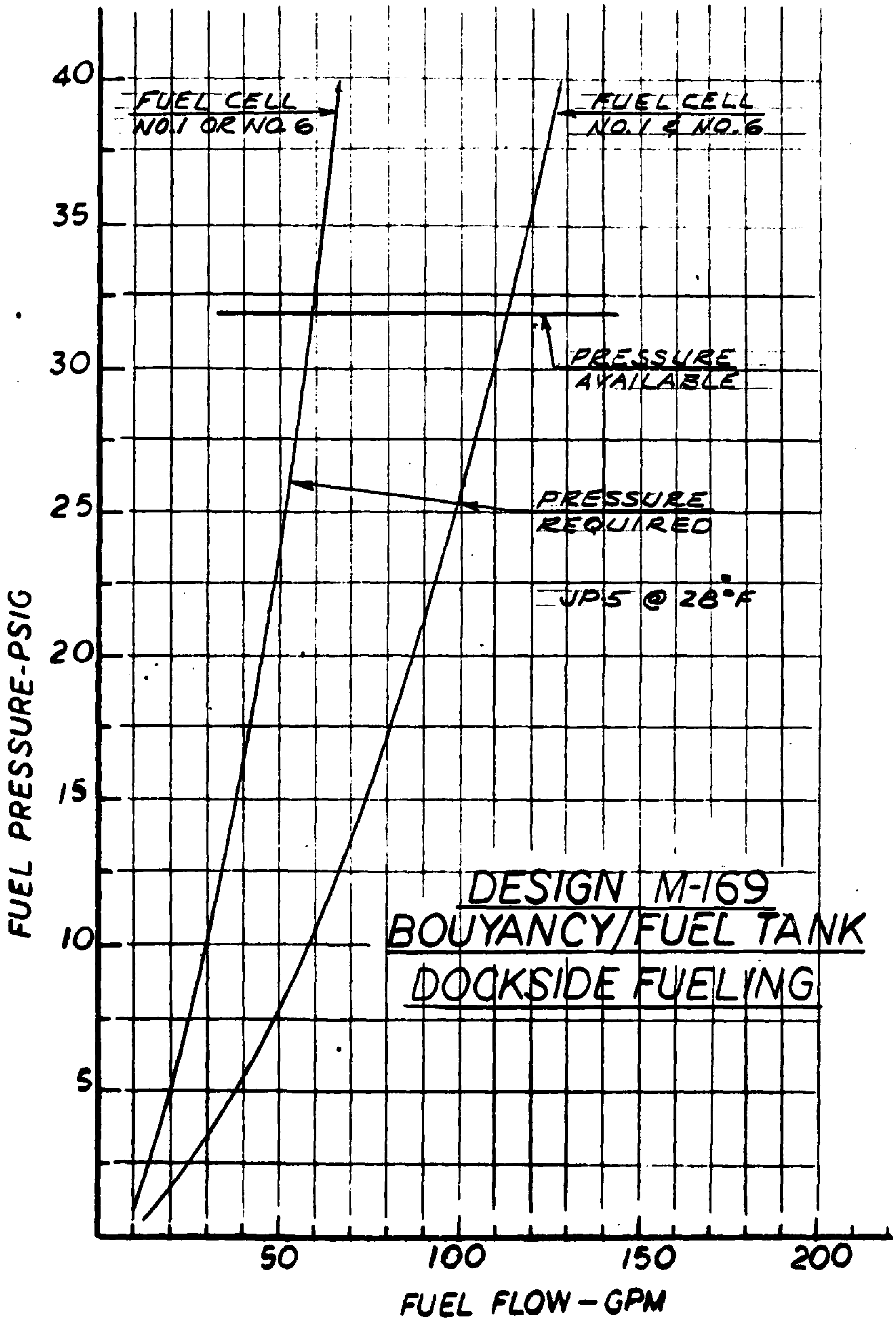


HULLBORNE FUEL TRANSFER

FROM B/F TANK CELLS 1& 6 TO HULL FWD TANK

(Compressed air to B/F tank Cells 2 & 5)

Figure 6-5



FUEL CELL NO.1 OR NO.6
FUEL CELL NO.1 & NO.6
PRESSURE AVAILABLE
PRESSURE REQUIRED
JP5 @ 28°F
DESIGN M-169
BOUYANCY/FUEL TANK
DOCKSIDE FUELING
40
35
30
25
20
15
10
5
FUEL PRESSURE-PSIG
50
100
150
200
FUEL FLOW—GPM

Figure 6-6

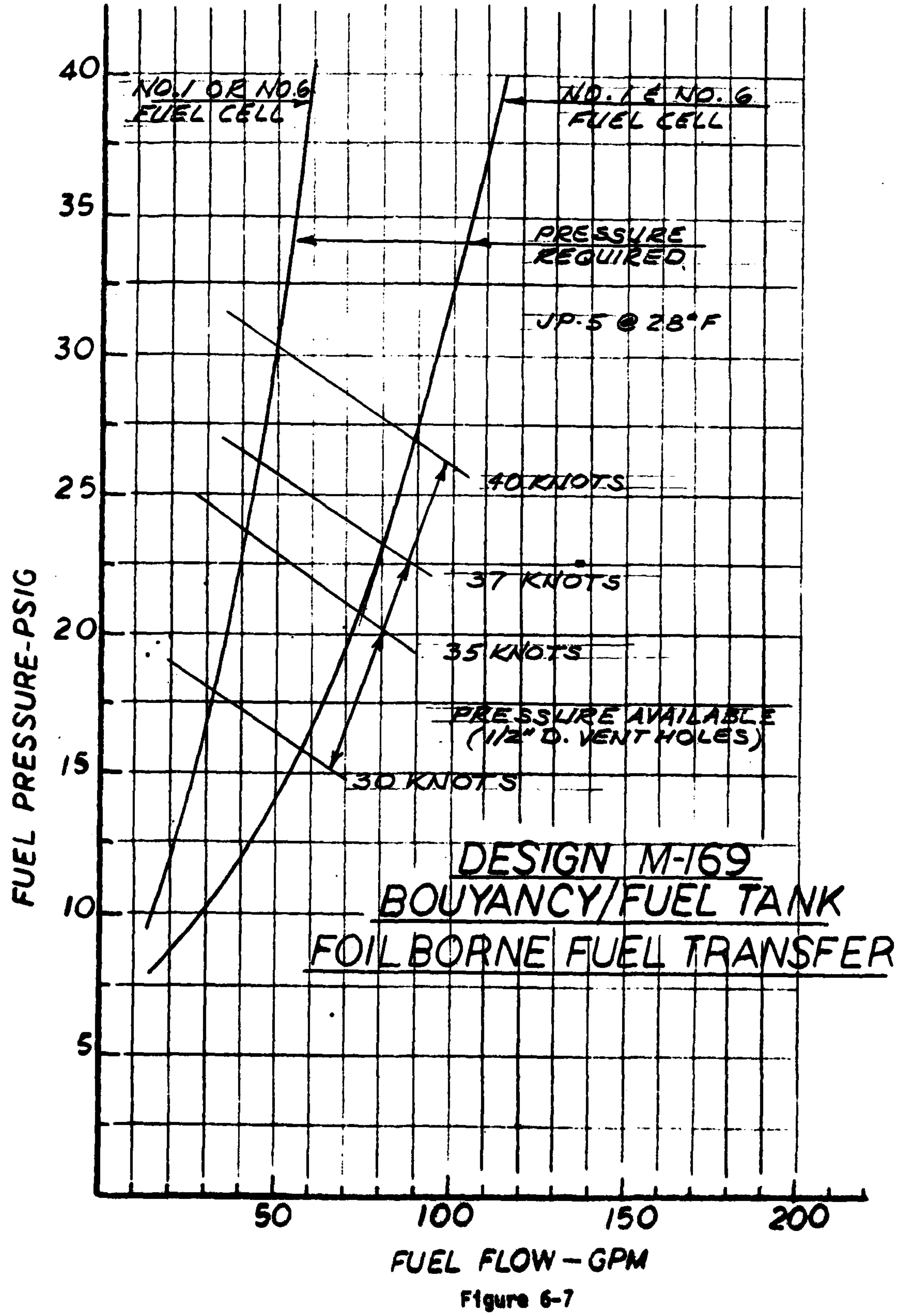

NO.1 OR NO.6
FUEL CELL
NO.1 & NO.6
FUEL CELL
PRESSURE
REQUIRED
JP-5 @ 28°F
40 KNOTS
37 KNOTS
35 KNOTS
PRESSURE AVAILABLE
(1/2" D. VENT HOLES)
30 KNOTS
DESIGN M-169
BOUYANCY/FUEL TANK
FOILBORNE FUEL TRANSFER
FUEL PRESSURE-PSIG
FUEL FLOW—GPM
40
35
30
25
20
15
10
5
50
100
150
200

Figure 6-7

6.1.1 (Cont'd) therefore requiring approximately the same time to effect a fuel transfer to the hull tanks. The flow rates are slightly less than previously indicated due to the fact that the size and length of piping is based on the revised piping as listed on Figure 6-8.

In addition, the pressure drops for the 1-1/2" flow meters, disconnect couplings, and 2-1/2" pressure regulators were taken directly from the vendor supplied curves and applied to each calculation.

From the preceding information the total pressure drop for fuel cell No. 1 and the combined drop for cells No. 1 and 6 were calculated. Figure 6-9 and 6-10 present the breakdown of losses for the various components in progressive flow rate increments. These figures are plotted as pressure required versus flow rate on Figures 6-6 and 6-7.

Losses thru the 1/2" holes were originally based on an orifice coefficiency of .61. The actual orifices are thick walled and submerged indicating that a value greater than .61 should be used. Reference 24 suggests .76 for a thick walled submerged orifice.

The differential pressure in the prismatic section of the pod will be the same thru out. Those holes (2 in No. 1 cell and 2 in No. 6 cell) in the forebody and afterbody will be treated as having a lower static pressure than those in the prismatic section by 1/2. No losses are considered for flow thru the cells. From a nomogram, the entrance and exist losses from each cell are figured as 5 and 10 equivalent feet respectively and equivalent lengths of piping thru voids as 5 feet each, for a total of 20 equivalent feet.

Dynamic pressure was calculated from the formula

$$P = 1/2\rho V^2 \text{ with } 1/2\rho = .9948$$

Therefore at 40K $P = .9948\ (40 \times 1.6839)^2/144 = 31.53$ psi

37	= 26.98
35	= 24.14
30	= 17.74

Ram pressure is obtained by combining the dynamic pressure with the static head for a nominal foilborne submergence of 7.5 feet.

$$\text{Static Head} = 7.5 \text{ Ft.} = \frac{7.5 \text{ Ft.} \times 64\#/\text{Ft.}^3}{144 \text{ in}^2/\text{Ft}^2} = 3.33 \text{ Psi}$$

EQUIVALENT FEET (Cell 1 or 6)

PIPING SIZE	1-1/2" x .049	1-1/4" x .049	2-1/2" x .120
Tank & Strut			
Piping	58.0	-	-
1-45^{o} Elbow 1-1/2"	2.0	-	-
1-90^{o} Elbow 1-1/2"	4.5	-	-
3-45^{o} Elbow 1-1/2"	4.5	-	-
Hull			
Piping	2.5	6.0	17.5
1 - Butterfly Valve	1.0	-	3.0
1 - Tee On Run	-	2.0	4.5
4 - 90^{o} Elbow 1-1/4"	-	14.0	-
2 - 90^{o} Elbow 2-1/2"	-	-	12.0
1 - 90^{o} Elbow 1-1/2"	4.5	-	-
3 - 90^{o} Bends 2-1/2"	-	-	10.5
	77	22	47.5
+ 10%	8	2	4.5
Total Equivalent Feet	85	24	52

FUEL SYSTEM PIPING

EQUIVALENT STRAIGHT PIPE FEET

Figure 6-8

M169 FUEL SYSTEM PRESSURE DROPS - NO. 1 or NO. 6 CELL JP-5 @ 28^{O}F

TUBE SIZE	GPM	$\frac{\Delta P}{100}$ psi	(1) $\frac{\Delta P}{85}$	(2) $\frac{\Delta P}{24}$	(3) $\frac{\Delta P}{52}$	(4) ΔP Flow Meter	(5) ΔP Q.D. CPLG	(6) ΔP Press Reg.	(7) 4+5+6
1.5" x .049" Wall	20	2.77	2.35			.14	.22		.365
	40	9.65	8.20			.47	.80		1.37
	60	20.02	17.02			1.04	1.90		3.64
	80	33.61	28.57			1.65	4.20		6.85
	100	50.23	42.70			2.59	4.80		8.99
1.25" x .049" Wall	20	7.1		1.70				.005	
	40	24.78		5.95				.10	
	60	51.40		12.34				.70	
	80	86.28		20.70				1.00	
	100	128.93		30.94				1.60	
2.875" x .120"Wall	20	.134			.07				
	40	.467			.24				
	60	.969			.50				
	80	1.626			.85				
	100	2.43			1.26				

TOTAL PRESSURE DROP

	DOCKSIDE FUELING	FOILBORNE TRANSFER	
GPM	Frict. = 1+2+3+7	Static Head	Total psi
20	4.485	7.50	11.99
40	15.76	7.50	23.26
60	33.50	7.50	41.00
80	56.97	7.50	64.47
100	83.89	7.50	91.39

FUEL SYSTEM PRESSURE DROPS, CELLS 1 or 6

Figure 6-9

M169 FUEL SYSTEM PRESSURE DROPS NO. 1 AND 6 CELLS JP5 @ $28^{O}F$

TUBE SIZE	GPM	ΔP 100	(1) ΔP 85	(2) ΔP 24	(3) ΔP 52	(4) ΔP Flow Meter	(5) ΔP Q.D. CPLG	(6) ΔP Press Reg.	(7) 4+5+6
1.5" x .049" Wall	10	.796	.68			.035	.04		.08
↓	20	2.77	2.35			.14	.22		.46
	30	5.75	4.89			.27	.46		2.27
	40	9.65	8.20			.47	.80		3.67
	50	14.42	12.26			.71	1.36		4.94
1.25" x .049" Wall	10			.49					
↓	20			1.70					
	30			3.54					
	40			5.95					
	50			8.89					
2.875" x .120" Wall	20				.07			.005	
↓	40				.24			.10	
	60				.50			.70	
	80				.85			1.00	
	100				1.26			1.60	

TOTAL PRESSURE DROP

GPM	DOCKSIDE FUELING Frict = 1+2+3+7	FOILBORNE TRANSFER Static Head	Total Psi
20	1.32	7.50	8.82
40	4.75	7.50	12.25
60	10.36	7.50	11.86
80	17.27	7.50	11.77
100	26.08	7.50	33.58

FUEL SYSTEM PRESSURE DROPS CELLS 1 and 6

Figure 6-10

6.1.1 (Cont'd)

For Forebody & Afterbody holes = 3.33/2 = 1.67 psi

Ram Press = Dyn & Static at 40 kts = 31.53 + 3.33 = 34.87 psi

37 kts = 26.98 + 3.33 = 30.31 psi

35 kts = 24.14 + 3.33 = 27.47 psi

30 kts = 17.74 + 3.33 - 21.07 psi

Certain assumptions were made in conjunction with the design conditions contemplated resulting in conservative generalized results. Principal among these criteria are:

(a) The sea water ballast duct through the void spaces is 4" O.D. x .125" Wall.

(b) Max craft speed is 37 knots and equal to $\approx$30 psi ram pressure. If there were no losses in the seawater line that would give a fuel flow for cells 1 & 6 of about 94 GPM. However there are losses and from previous calculations it appears that the fuel flow would be 84 GPM from cells 1 & 6 simultaneously. To simplify the calculations the assumption is made that the fuel flow rate is 84 GPM regardless of craft speed (30-40 knots).

(c) The assumption will also be made that the differential pressure causing flow thru the vent holes is also constant in the 30-40 knot speed range. The value chosen is 27 psi in the prismatic section and 28.67 in the fore and afterbody sections.

The flow through the 1/2" diameter holes was based upon the standard formula for flow through a thick walled submerged orifice:

q = $.76 A \sqrt{2gh}$ where

q = flow in cu. ft. per sec.

A = Area in square feet

h = head in feet

Converting to GPM the flow through the vent holes becomes:

For prismatic section - 20 holes	29 GPM/Hole
Forebody and afterbody 4 holes	30 GPM/Hole

Total SW flow = 84 + (20 x 29) + (4 x 30) = 784 GPM

Flow into Cell 1 = 784 GPM

Flow into Cell 2 & 3 = 784 - [42 + (2 x 30) + (2 x 29)] = 624 GPM

Flow into Cell 4 & 5 = 624 - (8 x 29) = 392 GPM

Flow into Cell 6 = 392 - (8 x 29) = 160 GPM

6.1.1 (Cont'd) Additional simplifications and conservatisms are incorporated into the pressure available.

1. Constant fuel flow regardless of craft speed.
2. Constant fuel flow whether pumping from one alone or two together.
3. Constant differential pressure to cause flow thru the drain holes.

The net results of these calculations are tabulated on Figure 6-11.

During ship check of the PCH-1, a random survey was made of several of the double bottom void areas to ascertain if any would be suitable for extended range fuel tanks. While such areas do exist, specifically those between frames 8 and 11, they are not suitable for use as fuel tanks without structural reinforcement and weld inspection.

6.1.2 Dockside Fueling - When fueling with 40 psi dockside pressure and pressure controlled to 32 psi (max) @ fuel transfer manifold the head to B/F tank is

$$24' = \frac{24 \times 62.4 \times .83}{144} = 8.6 \text{ psi}$$

$$\text{Seawater Head (displaced)} = 19\text{-}1/2' = \frac{19.5 \times 64}{144} = 8.66 \text{ psi}$$

Max. pres. in B/F tank = 32 + 8.6 - 8.66 = 31.94 psi

Figure 6-6 shows a dockside fuel flow of approximately 58 GPM per cell at this pressure.

Based upon the full B/F tank fuel capacity of 39.09 L.T. the approximate time to refuel under various combinations of cells would be approximately as follows:

Total capacity = 39.09 L.T. x 321.64 gal/ton = 12,573 gals.

No. of cells fueled simultaneously	
1	216 Min.
2	108 Min.
3	72 Min.
4 + 2	84 Min.
5 + 1	96 Min.
6	72 Min.

Inasmuch as the standard Navy refueling rate is 200 GPM at 40 psi no more than this amount could be taken on board. To allow for losses the above times are based upon a maximum fuel flow of 174 GPM

SEAWATER PRESSURE DROPS IN B/F TANK

		Cell 1				Cell 2 & 3			
SPEED-KNOTS	Ram Press Psig	Flow GPM	ΔP 100 ft	ΔP 20 ft	Press Avail Psig	Flow GPM	ΔP 100 ft	ΔP 20 ft	Press Avail
40	34.87	784	18.3	3.66	31.21	624	12.13	2.43	28.78
37	30.31				26.65				24.22
35	27.47				23.81				21.38
30	21.07	784			17.41	624			14.98
		Cell 4 & 5				Cell 6			
40	34.87	392	5.26	1.05	27.37	160	1.05	.21	27.52
37	30.31				23.17				22.96
35	27.47				20.33				20.12
30	21.07	392			13.93	160			13.72

NOTE: All calculations based upon 4" O.D. x .125" wall tubing interconnecting ballast lines and four 1/2" dia. vent holes in each cell.

Table based upon transferring fuel from cells No. 1 and 6 simultaneously.

SEAWATER PRESSURE DROP IN B/F TANK

Figure 6-11

6.2 Bilge and Ballast System - The ballasting system for the buoyancy/fuel tank is an integral system within the tank, having no connection to any portions of the hull system. The screened inlet of approximately 3½ inch diameter is located at the forward end of the nose cone.

No piping is required within the ballast cells themselves, but interconnecting pipes are run through each of the access compartments. In this manner, one inlet serves all six ballast cells. No valving is required as rate of flow is regulated by the fuel cell control valves.

A motor operated valve is located in the ballast line at the nose and tail of the buoyancy/fuel tank to provide a measure of control during ballasting and deballasting operations.

The four void spaces are interconnected by drain lines thru the fuel cells to a bilge pump located in the space below the strut. Each compartment is fitted with a bilge alarm, the one located in the compartment below the strut provides automatic starting of the pump. Remote control of the pump is also provided at the fuel management station.

6.3 Compressed Air System - The existing ships H.P air system will be modified to provide the deballasting function for the Buoyancy/Fuel tank. Deballasting is required foilborne to reduce dynamic lift, and dockside to avoid overloading the crane when lifting the craft from the water. The foilborne function is provided by the shipboard system while the dockside service is provided by a shore air connection connected to the deballasting manifold on the ship.

The modifications to the system include the addition of a purification chamber in series with the existing compressor discharge piping to lower the dew point to -50^{0}F to preclude water being carried over into the fuel cells. This also supplies divers breathing air if desired. An existing 1.5 ft^3 bottle will be supplemented by 7 additional 1.5 ft^3 air flasks for a total storage capacity of 12 ft^3. The storage bottles can be charged in 5 hours by the H/P air compressor. The replaceable cartridge in the purification chamber is good for 4 complete chargings of the 12 ft^3 storage flasks. High pressure (3000 psig) air is piped to a 3000/32 psig pressure reducing valve and backed up by a pop safety valve. The 32 psig supply is piped to a "Y" branch manifold so that only two of the six fuel tanks may be simultaneously deballasted while foilborne. The compressed air is routed to the fuel cells thru check valves to prebent fuel backup into the compressed air system. The fuel piping within the B/F tank strut is utilized for the compressed air system.

Dockside air at a nominal 100 psig is available for dockside deballasting prior to placing the craft in the maintenance stand. Dockside air usually contains some freewater and has a fairly high dew point. In order to avoid introducing water into the ships tanks, a dockside skid mounted air drier is required. An inlet and discharge filter are part of this assembly. The dry (-50^{0}F dew point) air is connected to the craft's shore air connection and piped to a 100/32 psig pressure reducing valve which is "teed" into the deballast manifold.

To preclude creating an unstable condition by deballasting an excessive number of cells only two flexible connections are included in the compressed air supply to the deballast manifold. By using only six of the eight air flasks it is possible to pressurize two fuel cells to 32 psig in seven minutes with the ram pressure shut-off valve closed. Deballasting can be accomplished with the ram pressure shut-off valve open, but it would take considerably more time as the differential pressure would be very low. As the air pressure in a deballasted tank is higher than ram pressure, it is possible to transfer fuel while foil-

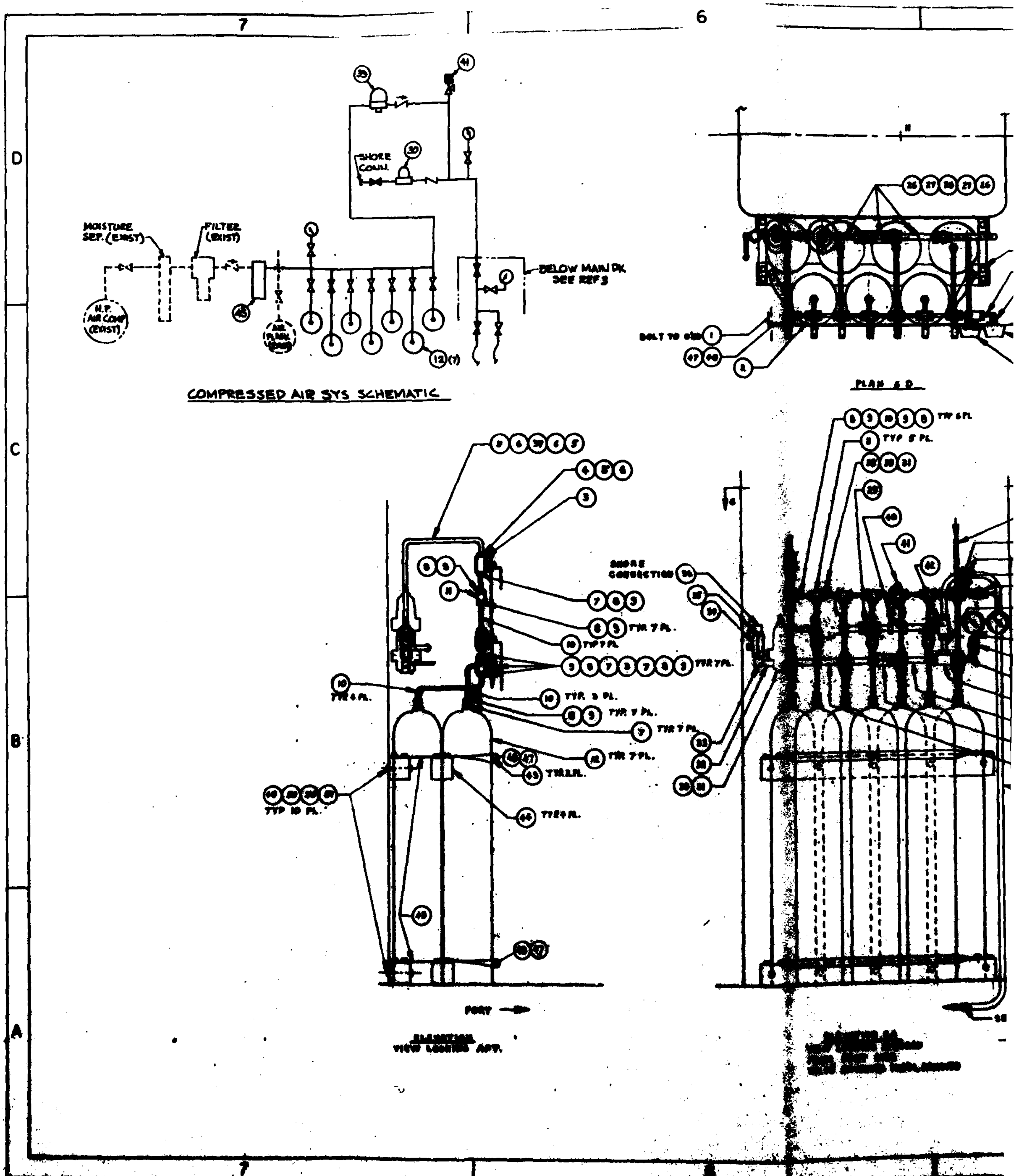
6.3 borne and not have any recompression and subsequent loss of buoyancy.
(Cont'd) It will be necessary to deballast all cells prior to lifting the craft into the maintenance stand to avoid overloading the crane and the hull. When this evolution is carried out it will be necessary to have the lifting slings attached and under a strain as the deballasting operation procedes. Dockside deballasting is done with dockside air and should be accomplished in less than 20 minutes.

The compressed air system is shown on Figure 6-12.

6.4 Hydraulic System - Based on the rudder requirements for the B/F tank and other information received to date, it is proposed to utilize a spare incidence actuator from the PGH-1 "FLAGSTAFF" as the B/F tank rudder actuator. Both the installed unit and a spare will be overhauled and converted for SKYDROL 500B. The requirements for $\pm 10^{\circ}$ rudder throw at a rate three times that of the existing forward strut steering actuator can be met with this actuator. This is based on holding a ventilated load of 1150 PSF with a service factor of 1.46 with 2400 psid across the actuator. The flow rate for this condition is 26 GPM. When this rate is added to the existing system demands and the RMS flow rate determined, it is apparent that the standby foilborne hydraulic pump will have to be operated at all times. In an effort to alleviate this situation, a 600 cubic inch accumulator has been sized and added to the system in the B/F tank rudder actuator. During initial sea trials the standby foilborne hydraulic pump should be in operation. Once the ship has been shaken down, tests can be conducted with the standby pump secured to check the adequacy of the accumulator installation. The sizing criteria chosen was one actuator stroke in 670 milliseconds.

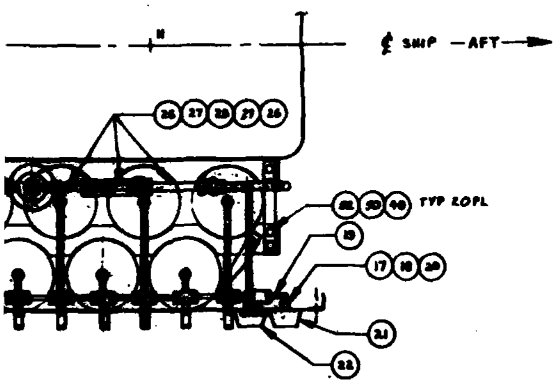
Actuator seal drains are routed to the foilborne reservoir. The accumulator charging connection and gage are to be located in the sonar trunk fuel management area.

High pressure quick disconnect fittings are located at the actuator and at the B/F tank-strut intersection as an aid in assembly and to prevent draining long lengths of lines during maintenance and test operations. The installation of the hydraulic system in the B/F tank is shown on Figure 6-13.

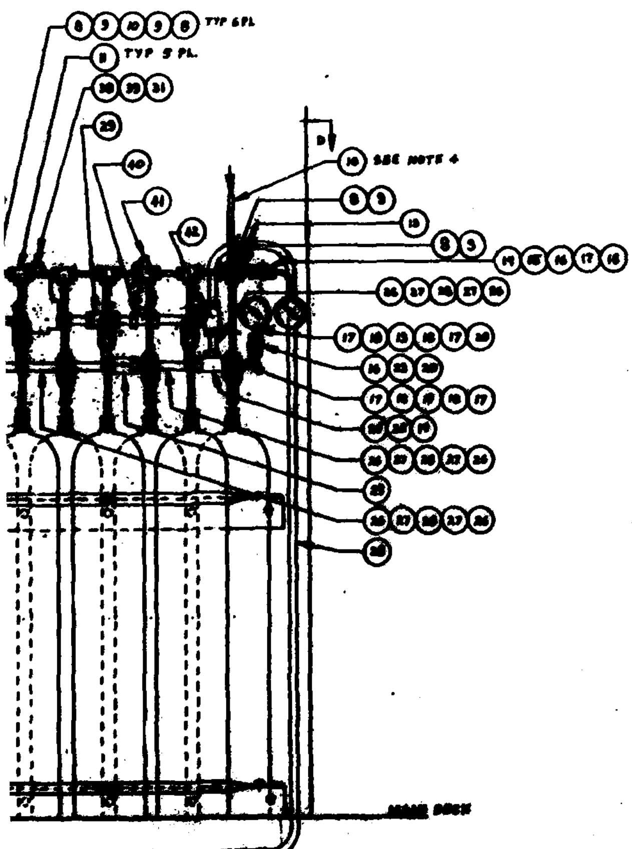

7
6
D
C
B
A
SHORE CONN.
MOISTURE SEP. (EXIST)
FILTER (EXIST)
H.P. AIR COMP (EXIST)
BELOW MAIN DK SEE REF 3
COMPRESSED AIR SYS SCHEMATIC
SHORE CONNECTION
PORT

5

4



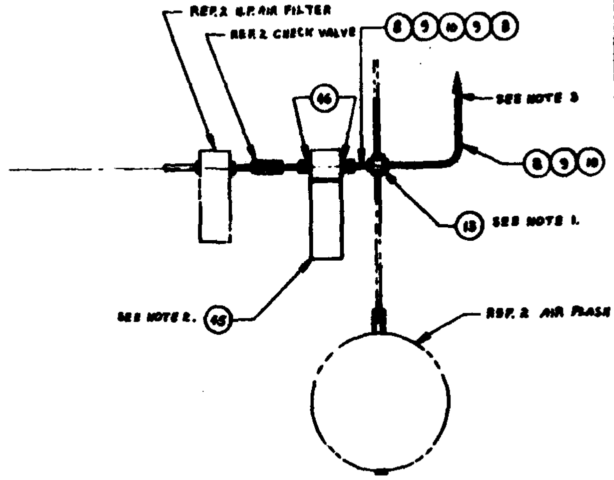
PLAN 6 D



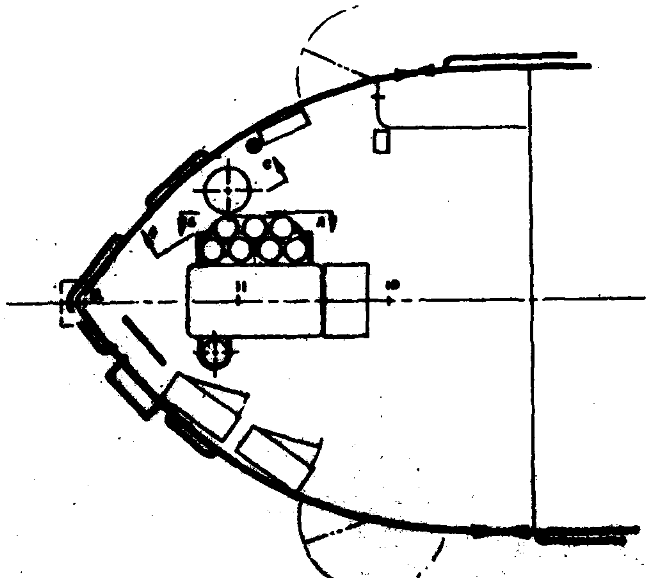
ELEVATION 6A

GENER

1. REPLACE EX
2. ADD PURIFI SYSTEM AS
3. CONTINUE ELEVATION
4. CONTINUE H.P. AIR SYS
5. CONTINUE REF. 3. ZON
6. SUPPORT PI AND SHIP P
7. CEMENT ½

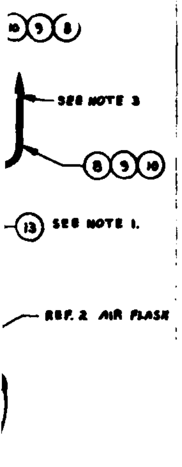


ELEVATION 4C
VIEW LOOKING OUTBOARD
PORT SIDE (REF. 2 ELEVATION 9-C)



PLAN AT MAIN DECK

3 | 2



GENERAL NOTES

1. REPLACE EXISTING TEE (P841 OF REF 2) WITH CROSS, ITEM 13.
2. ADD PURIFICATION CHAMBER TO EXISTING COMPRESSED AIR SYSTEM AS SHOWN, ITEM 45.
3. CONTINUE OVERHEAD TO H.P. MANIFOLD SHOWN IN ELEVATION 6A.
4. CONTINUE OVERHEAD FROM CROSS ADDED TO EXISTING H.P. AIR SYSTEM. SEE ELEVATION 4C.
5. CONTINUE OVERHEAD TO H.P. MANIFOLD SHOWN IN REF. 3. ZONE 3D.
6. SUPPORT PIPING AS REQUIRED USING STANDARD CLAMPS AND SHIP PRACTICE.
7. CEMENT 1/4" RUBBER CUSHION TO DECK UNDER CYLINDERS

LIST OF MATERIAL

ITEM NO.	QTY.	DESCRIPTION	PART NO.	VENDOR	REMARKS
1	2	ANGLE 2"x2"x1/4"	ALUM AL. 6061-[illegible]		L= 3'-0"
2	1	PLATE (MOUNTING FOR VALVES)	ALUM AL. 6061-[illegible]		[illegible]
3	8	BALL VALVE 3/4"	HP 36 GT 3/4"	JAMESBURY	PANEL MOUNT
4	1	1/2" PIPE TO 3/4" TUBE ADAPTER	2021-8-12C	AEROQUIP	
5	1	NUT 3/4"	1290-12C	AEROQUIP	
6	1	SLEEVE 3/4"	900605-12C	AEROQUIP	
7	22	1/2" PIPE TO 1/2" TUBE ADAPTER	2021-8-8C	AEROQUIP	
8	46	NUT 1/2"	1290-8C	AEROQUIP	
9	46	SLEEVE 1/2"	900605-8C	AEROQUIP	
10	8FT	1/2" TUBE	CRES TYPE 304		.065 WALL
11	6	TEE 1/2" TUBE	2033-8-8C	AEROQUIP	
12	7	CYLINDER DOT 3AA ULTRA HP.	35023	TAYLOR-WHARTON CO.	NOMINAL 1.5 FT³ WATER
13	2	CROSS 1/2" TUBE	2020-8-8C	AEROQUIP	
14	1	3/8" PIPE TO 1/2" TUBE ADAPTER	2021-6-8C	AEROQUIP	
15	1	NEEDLE VALVE 5000 PSI	FIG. 1702 3/8" NPT. FEM.	LUNKENHEIMER	
16	2	3/8 PIPE TO 1/4 TUBE ADAPTER	2021-6-4C	AEROQUIP	
17	6	NUT 1/4"	1290-4C	AEROQUIP	
18	6	SLEEVE 1/4"	900605-4C	AEROQUIP	
19	AS REQ	1/4 TUBE	CRES TYPE 304		
20	2	ELBOW 1/4" TUBE TO 1/4 MT. PIPE	2025-6-4C	AEROQUIP	
21	1	GAUGE 0-4000 PSIG 3 1/2"	TYPE 430	HELICOID	1/4" MALE NPT ON BAC
22	1	GAUGE 0-60 PSIG 3 1/2"	TYPE 430	HELICOID	1/4" MALE NPT ON BAC
23	1	NEEDLE VALVE 200 PSI	FIG. 986 3/8" NPT FEM.	LUNKENHEIMER	
24	1	TEE - 1" TUBE / 1" PIPE	2023-16-16C	AEROQUIP	
25	1	REDUCER 1-11/2 2 TO 3/8-18 R	2081-16-6C	AEROQUIP	
26	12	NUT 1"	1290-16C	AEROQUIP	
27	12	SLEEVE 1"	900605-16C	AEROQUIP	
28	24FT	TUBE 1" OD	CRES TYPE 304		.065 WALL
29	2	CHECK VALVE	293 T1-16TT	CIRCLE SEAL CONTROLS	
30	1	REGULATOR	830-0183	CASHCO	
31	2	1" PIPE TO 1" TUBE ADAPTER	2021-16-16C	AEROQUIP	
32	1	PIPE NIPPLE 1"			SCHED 40
33	1	ELBOW - 1" EXT PIPE / 1" INT PIPE	2009-16-16C	AEROQUIP	
34	1	BALL VALVE 1"	HP 36 GT 1"	JAMESBURY	
35	1	CAP 1" PIPE			
36	1	ELBOW - 1" INT PIPE	2005-16-16C	AEROQUIP	
37	4FT	3/4" TUBE	CRES TYPE 304		.065 WALL
38	1	1" PIPE TO 3/4" TUBE ADAPTER	2021-16-12C	AEROQUIP	
39	1	REGULATOR	HP-3-830-6200	CASHCO	
40	1	TEE - 1" TUBE / 1" PIPE	2023-16-16C	AEROQUIP	
41	1	RELIEF VALVE	FIG. 1825-1"	LUNKENHEIMER	
42	1	TEE - 1" TUBE	2033-16-16C	AEROQUIP	
43	[illegible]	1 1/2" x 1/4" FLAT BAR - STEEL			
44	4	WOOD [illegible] LONG			[illegible] FIR
45	1	PURIFICATION CHAMBER	[illegible]-200 / PC [illegible] CARTRIDGE	[illegible]	
46	2	[illegible] TO 1/2" 37° FLARE	[illegible]-6-8C	AEROQUIP	
47	8	NUT	STAINLESS STEEL 18-8	COM'L	[illegible]
48	8	BOLT	STAINLESS STEEL 18-8	COM'L	[illegible]
49	30	NUT	STAINLESS STEEL 18-8	COM'L	[illegible]
50	30	WASHER	STAINLESS STEEL 18-8	COM'L	[illegible]
51	10	BOLT	STAINLESS STEEL 18-8	COM'L	[illegible]
52	20	LAG BOLT	STAINLESS STEEL 18-8	COM'L	[illegible]

3

2 | 1

LIST OF MATERIAL

ITEM NO.	QTY.	DESCRIPTION	PART NO.	VENDOR	REMARKS
1	2	ANGLE 2"x2"x1/4"	ALUM AL. 6061-T6		L- 3'-0"
2	1	PLATE (MOUNTING FOR VALVES)	ALUM AL. 6061-T6		1/4"x4'-0"x14" - 3/4" FLA TOP & BOT.
3	8	BALL VALVE 1/2"	[illegible] 36 GT 1/2"	JAMESBURY	PANEL MOUNT
4	1	1/2" PIPE TO 3/4" TUBE ADAPTER	2021-8-12C	AEROQUIP	
5	1	NUT 3/4"	1250-12C	AEROQUIP	
6	1	SLEEVE 3/4"	900605-12C	AEROQUIP	
7	22	1/2" PIPE TO 1/2" TUBE ADAPTER	2021-8-8C	AEROQUIP	
8	46	NUT 1/2"	1250-8C	AEROQUIP	
9	46	SLEEVE 1/2"	900605-8C	AEROQUIP	
10	8FT	1/2" TUBE	SSES TYPE 304		.065 WALL
11	6	TEE 1/2" TUBE	2033-8-8C	AEROQUIP	
12	7	CYLINDER DOT 3AA ULTRA [illegible]	[illegible]23	TAYLOR-WHARTON CO.	NOMINAL 1.5 FT³ WATER
13	2	CROSS 1/2" TUBE	2050-8-8C	AEROQUIP	
14	1	3/8" PIPE TO 1/2" TUBE ADAPTER	2021-6-8C	AEROQUIP	
15	1	NEEDLE VALVE 5000 [illegible]	FIG. 1782 3/8" NPT. FEM.	LUNKENHEIMER	
16	2	3/8 PIPE TO 1/4 TUBE ADAPTER	2021-6-4C	AEROQUIP	
17	6	NUT 1/4"	1250-4C	AEROQUIP	
18	6	SLEEVE 1/4"	900605-4C	AEROQUIP	
19	AS REQD	1/4 TUBE	SSES TYPE 304		
20	2	ELBOW 1/4" TUBE TO 3/8 INT. [illegible]	2025-6-4C	AEROQUIP	
21	1	GAUGE 0-4000 PSIG	TYPE 430	HELICOID	1/4" MALE NPT ON BACK
22	1	GAUGE 0-60 PSIG	TYPE 430	HELICOID	1/4" MALE NPT ON BACK
23	1	NEEDLE VALVE 200 PSI	FIG. 386 3/8" NPT FEM.	LUNKENHEIMER	
24	1	TEE - 1" TUBE / 1" PIPE	2033-16-16C	AEROQUIP	
25	1	REDUCER 1-11 1/2 E TO 3/8-18 [illegible]	2021-16-6C	AEROQUIP	
26	12	NUT 1"	1250-16C	AEROQUIP	
27	12	SLEEVE 1"	900605-16C	AEROQUIP	
28	24FT	TUBE 1" OD	SSES TYPE 304		.083 WALL
29	2	CHECK VALVE	273T1-16TT	CIRCLE SEAL CONTROLS	
30	1	REGULATOR	830-0183	CASHCO	
31	2	1" PIPE TO 1" TUBE ADAPTER	2021-16-16C	AEROQUIP	
32	1	PIPE NIPPLE 1"			SCHED 40
33	1	ELBOW - 1" EXT PIPE / 1" INT PIPE	2026-16-16C	AEROQUIP	
34	1	BALL VALVE 1"	[illegible] 36 TT 1"	JAMESBURY	
35	1	CAP 1" PIPE			
36	1	ELBOW - 1" EXT PIPE	2027-16-16C	AEROQUIP	
37	4FT	3/4" TUBE	SSES TYPE 304		.065 WALL
38	1	1" PIPE TO 3/4" TUBE ADAPTER	2021-16-12C	AEROQUIP	
39	1	REGULATOR	[illegible] 830-6200	CASHCO	
40	1	TEE - 1" TUBE / 1" PIPE	2037-16-16C	AEROQUIP	
41	1	RELIEF VALVE	FIG. 1626 - 1"	LUNKENHEIMER	
42	1	TEE - 1" TUBE	2033-16-16C	AEROQUIP	
43	20FT	1 1/2" x 1/4" FLAT BAR - STEEL			
44	4	WOOD 4"x4"x6' LONG			DOUG. FIR
45	1	PURIFICATION CHAMBER	[illegible] / [illegible] CARTRIDGE	[illegible]	
46	2	SAE O-RING TO 1/2" 37° FLARE	[illegible]-8-8C	AEROQUIP	
47	8	NUT	STAINLESS STEEL 18-8	COM'L	1/2" HEX
48	8	BOLT	STAINLESS STEEL 18-8	COM'L	1/2" R.H 1"LG
49	20	NUT	STAINLESS STEEL 18-8	COM'L	1/4" HEX
50	20	WASHER	STAINLESS STEEL 18-8	COM'L	1/4"
51	10	BOLT	STAINLESS STEEL 18-8	COM'L	1/4" HEX HD 5"LG
52	20	LAG BOLT	STAINLESS STEEL 18-8	COM'L	1/4" 4" LG

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROV.

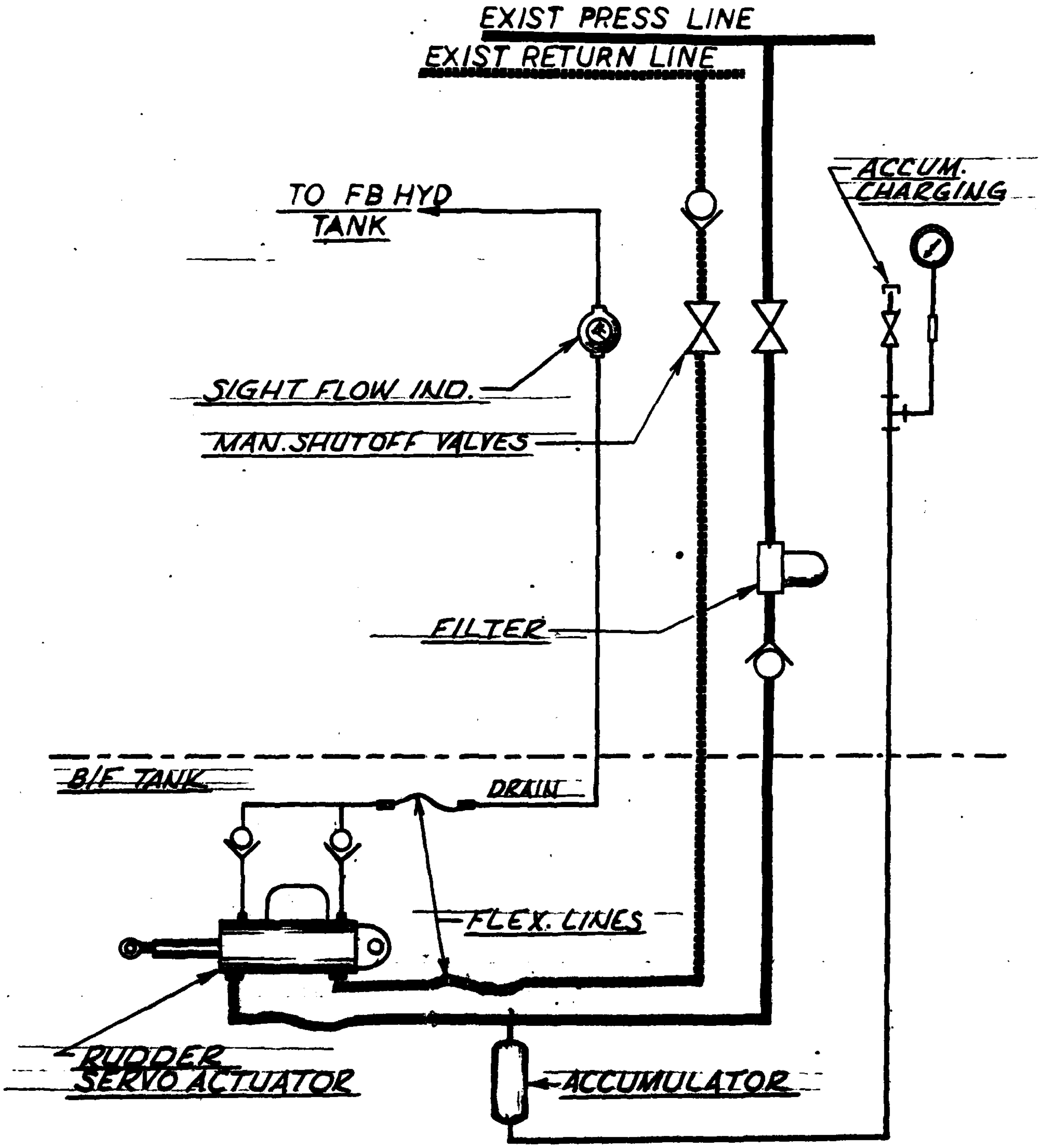
D

C

B

FIGURE G-12

	TITLE	REF. DWG. NO.
1	GENERAL ASS'Y [illegible]	[illegible]
2	[illegible] AIR [illegible]	[illegible]
3	[illegible]	[illegible]



HYDRAULIC SYSTEM MODIFICATION

Figure 6-13

SECTION 7

ELECTRICAL/ELECTRONIC SYSTEMS

7.0 Modifications to the Electrical/Electronic Systems are minimal and are described below.

7.1 Fuel System - High level float switches are to be installed in each of the two hull fuel tanks. These switches are to be connnected to a normally open motor operated valve, closing when the switches indicate that both tanks are full. An override is to be included to permit closing the valve during buoyancy/fuel tank filling operations.

Fuel flow transducers are located in the fill lines to each tank fuel cell and a display panel indicates fuel quantities in and out of each cell.

7.2 Steering System - The B/F Tank rudder requires an input from the existing helm synchro to be fed to a new signal amplifier, which in turn controls the rudder actuator servo-valve. This modification is shown on Figure 7-1. Further investigation of turning characteristics may warrant the inclusion of a redundant system for the aft rudder.

In order to prevent overloading the aft foil and strut, load cells are incorporated into the B/F tank fitting which feeds a signal to the steering actuator to compensate for the yaw movement.

7.3 Fathometer - The fathometer transducer presently installed in the forebody of the forward pod is to remain. However, a duplicate unit is to be installed in the buoyancy/fuel tank in the void space between cells 1 and 2. The tank mounted transducer is connected to the Depth Recorder and the hull transducer cable is disconnected, but stowed in place for future reconnection.

7.4 Ballast System - The ballast system requires the installation of two shut-off valves in the B/F tank. There are to be remotely controlled motor operated butterfly valves, and will require necessary wiring and controls.

7.5 Bilge System - The B/F tank bilge system includes bilge alarms in five tank compartments and a bilge pump located in the center compartment.

7.6 Tank Control Panel-The control panel includes the necessary switches, indicator lights, relays, etc., to provide the following:

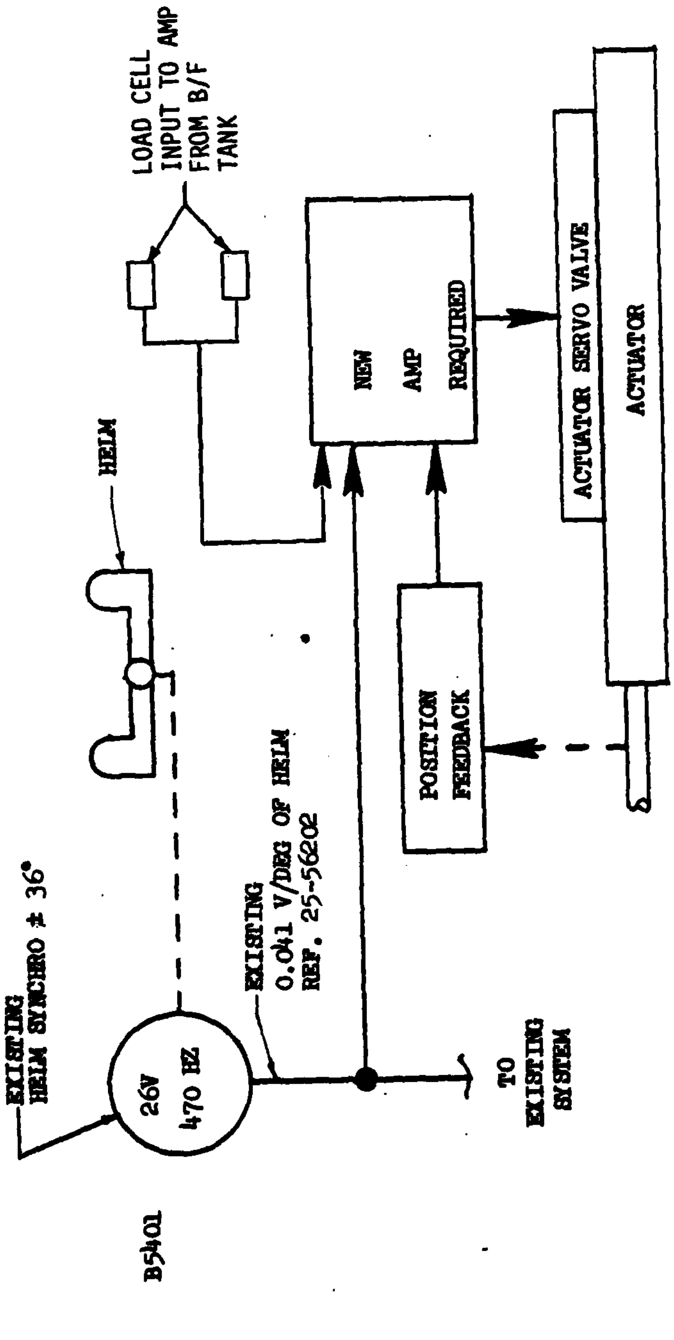
Bilge alarm indicator lights

Fuel M.O. valve control and position indication

S.W. M.O. valve control and position indication

Fuel Sys. Tank relief valve alarm

Hydraulic filter alarm



STEERING SYSTEM MODIFICATION

FIGURE 7-1

7.7 Electrical Power Requirements - The following items require power sources from the ship's distribution system:

B/F Tank Fuel Pump

B/F Tank Bilge Pump

Management Station Exhaust Fan

Tank Control Panel

Fuel Flow Indication System

SECTION 8

RUDDER AND STEERING - AFT

8.0 The added rudder aft has been incorporated to perform two functions. It serves both to improve the craft maneuverability, Section 3.6, and also to provide statical stability for the B/F tank during maneuvering operations.

In order to provide sufficient lateral area for stability it becomes necessary to install a rudder blade both above and below the B/F tank. Similarly, due to the pitching moment developed, horizontal fins are also incorporated.

The rudder, Figure 8-1, would be of all welded construction, fabricated from HY-80 steel as shown.

The steering system aft is integrated with the steerable forward strut, taking control commands from the same helm synchro and feeding them to a similar hydraulic actuator servo valve. The strut locking mechanism, however, is not required on the aft rudder. The steering actuator and quadrant installation are also shown in Figure 8-1.

It is also anticipated that the rudder motion will be activated by load cells within the aft strut attachment fitting in order to relieve yaw moment loads on the aft foil and struts. Without this feature it is possible that the struts could exeed the maximum allowable stress level during certain maneuvers.

AD-A146 099 BASELINE DESIGN REPORT OF EXTENDED PERFORMANCE HYDROFOIL PROGRAM PCH 1 FE (U) GRUMMAN AEROSPACE CORP BETHPAGE NY 15 NOV 81 MAR 1373 921 1 N00600 76 C 0246

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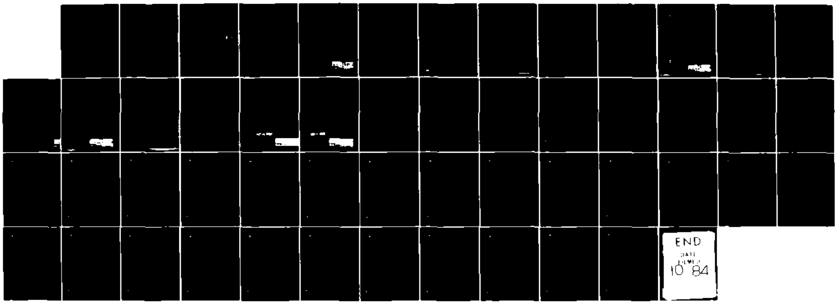

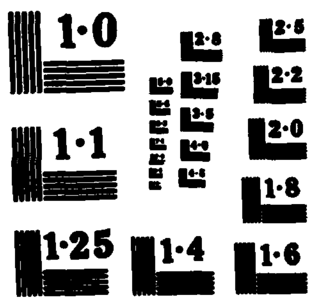
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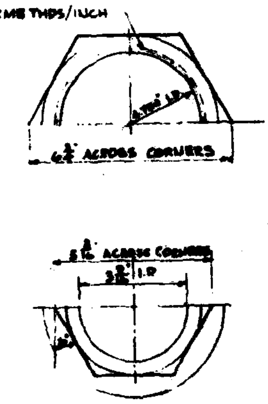
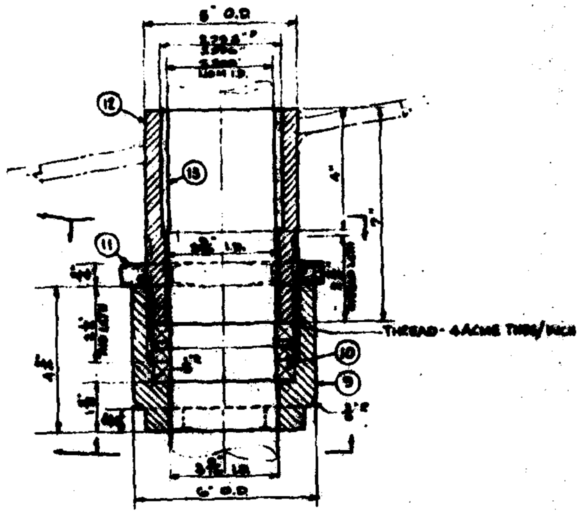
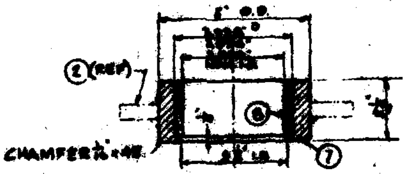
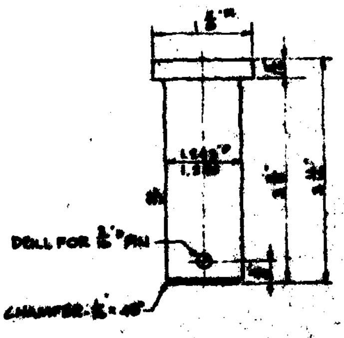




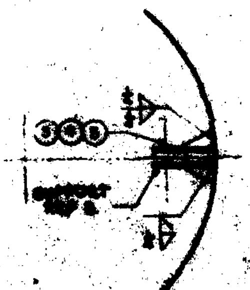
DET 6C
STUFFING BOX
SCALE: 6"=1'-0"



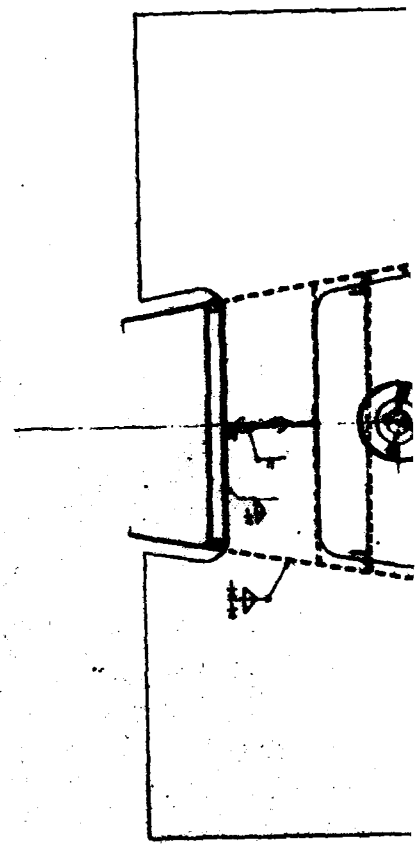
DET 6B
INTERIOR BEARING
SCALE: 6"=1'-0"

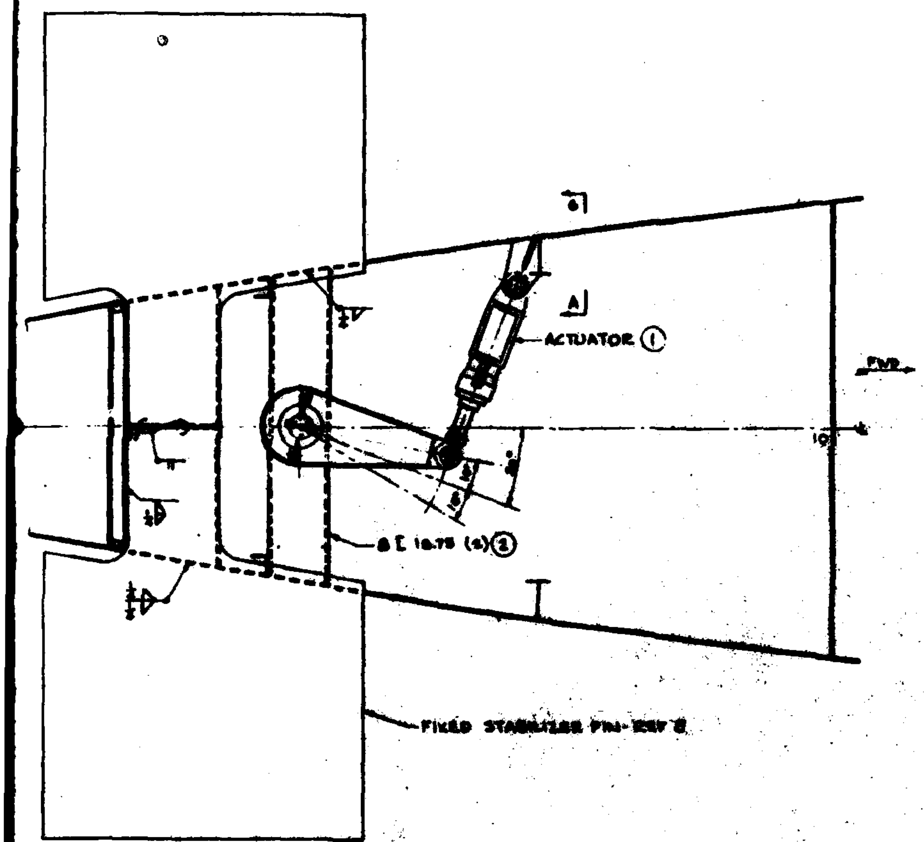


DET 7A
ACTUATOR PIN 5
SCALE: FULL

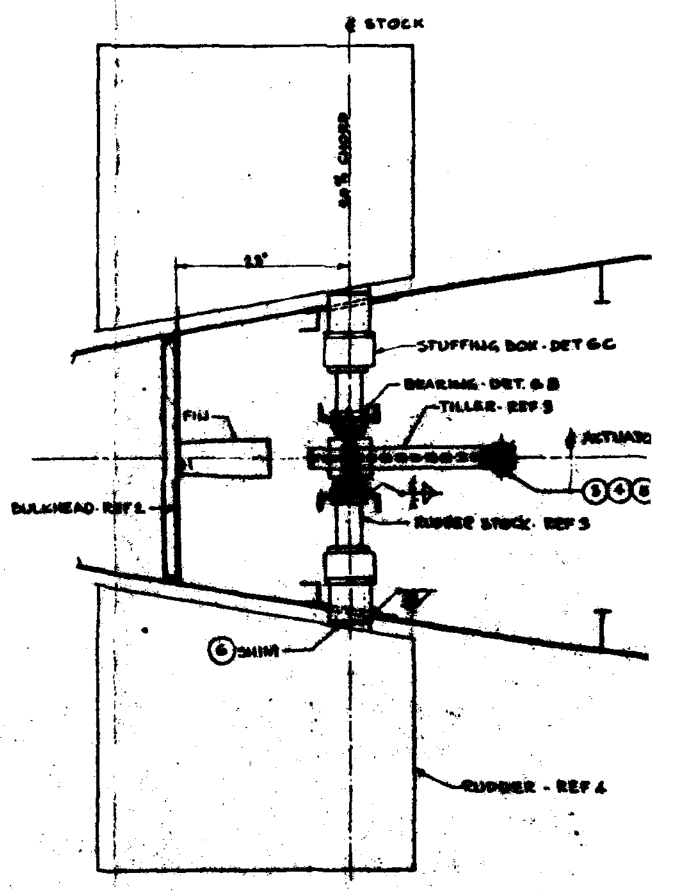


ACTUATOR SUPPORT

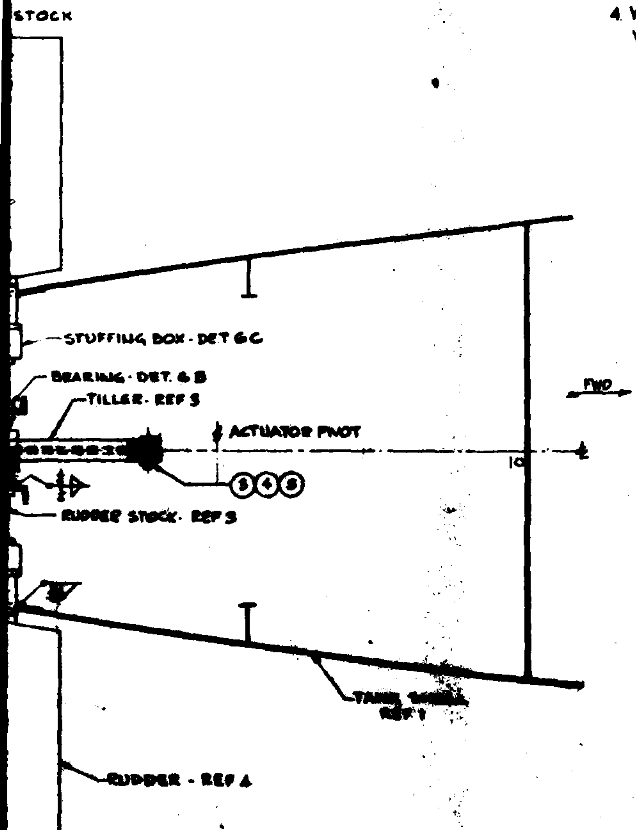




PLAN AT ℄



ELEVATION AT ℄



ELEVATION AT ℄

GENERAL NOTES

1. STUFFING BOXES AND BEARINGS TO BE LINE REAMED AFTER COMPLETION OF WELDING.
2. WELD JOINTS TO BE IN ACCORDANCE WITH MIL STD 0022C (SH).
3. FABRICATION, WELDING & INSPECTION TO BE IN ACCORD. WITH MIL-STD-1688(SH).
4. WELDING PROCESSES & FILLER MATERIALS TO BE IN ACCORD. WITH TABLE VI OF MIL-STD-1688(SH).

LIST OF MATE

ITEM NO.	QTY REQD	NOMENCLATURE TYPE NUMBER	NOMENCLATURE ITEM NAME
1	1		ACTUATOR - STEERING
2	2	STEEL	RUDDER SUPPORT
3	2	CRES 17-4PH	PIN
4	2	BRONZE	WASHER
5	2	CRES	SPLIT PIN
6	2	CRES-18-8	SHIM
7	4	STEEL-1018	BEARING HOUSING
8	2	DURALON	BEARING [illegible]
9	2	BRONZE	GLAND NUT
10	11 FT	[illegible]	PACKING
11	2	BRONZE	LOCK NUT
12	2	STEEL-1018	STUFF. BOX/BEARING
13	2	DURALON	BEARING [illegible]

REFERENCES

NO	TITLE	[illegible]
1	[illegible]	[illegible]
2	[illegible]	[illegible]
3	[illegible]	[illegible]
4	[illegible]	[illegible]
5	[illegible]	[illegible]
6		

4567

[illegible]RAL NOTES

[illegible] BEARINGS TO BE LINE REAMED [illegible]F WELDING.

[illegible]CCORDANCE WITH MIL STD 0022C (SH).

[illegible] & INSPECTION TO BE IN ACCORD. [illegible]

[illegible] FILLER MATERIALS TO BE IN ACCORD. [illegible] STD-1688(SH).

LIST OF MATERIALS						
[illegible]	[illegible]	NOMENCLATURE		DRAWING OR SPEC. NO.	REMARKS
		[illegible]	ITEM NAME		
[illegible]	1		ACTUATOR-STEERING	7-3475-6	EXIST.-LIONEL PACIFIC
[illegible]	[illegible]	[illegible]	RUDDER SUPPORT	ASTM A36	8 [18.75 L= 3'-9"
[illegible]	[illegible]	[illegible] 17-4PH	PIN	AMS 5643	DET 7A
[illegible]	[illegible]	[illegible]	WASHER		1¼" ID x 2" OD x ⅛" THK
[illegible]	[illegible]	[illegible]	SPLIT PIN		⅜" x 2" LG.
[illegible]	[illegible]	[illegible]	SHIM		5⅞" OD x 3⅞" ID t= ⅛ MIN
[illegible]	[illegible]	[illegible]-1018	BEARING HOUSING	ASTM A519	5" OD x 3⅞" ID x 2⅝" LONG
[illegible]	[illegible]	[illegible]	BEARING (REXNORD)		HEAVY WALL-3.000 ID-L-2⅝"
[illegible]	[illegible]	[illegible]	GLAND NUT	COM'L	6" D x 4⅝" LONG
[illegible]	[illegible]	[illegible]	PACKING	387-F	⅝" SQ-ANCHOR PACKING CO.
[illegible]	2	[illegible]	LOCK NUT	COM'L	5" HEX
[illegible]	2	STEEL-1018	STUFF. BOX/BEARING	ASTM A519	6" OD x 3⅞" ID x 7" LONG
[illegible]	2	DURALON	BEARING (REXNORD)		HEAVY WALL-3.500" I.D.-L-4"

REVISIONS				
ZONE	LTR	DESCRIPTION	APP'D	DA[illegible]

REFERENCES		
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

FIGURE 8-1

SECTION 9

MODIFICATIONS TO EXISTING SHIP

9.0 The modifications to the existing PCH-1 Mod 1 to install the buoyancy/fuel tank require extensive structural alterations as well as system and outfitting changes.

9.1 Foil System - As the existing aft foil/strut array is considered to be structurally satisfactory, the only modification required is the addition of a fitting to be attached to the underside of the foil as indicated on Figure 5-1. The fitting is to be faired into the existing structure to minimize the possibility of increased drag and cavitation.

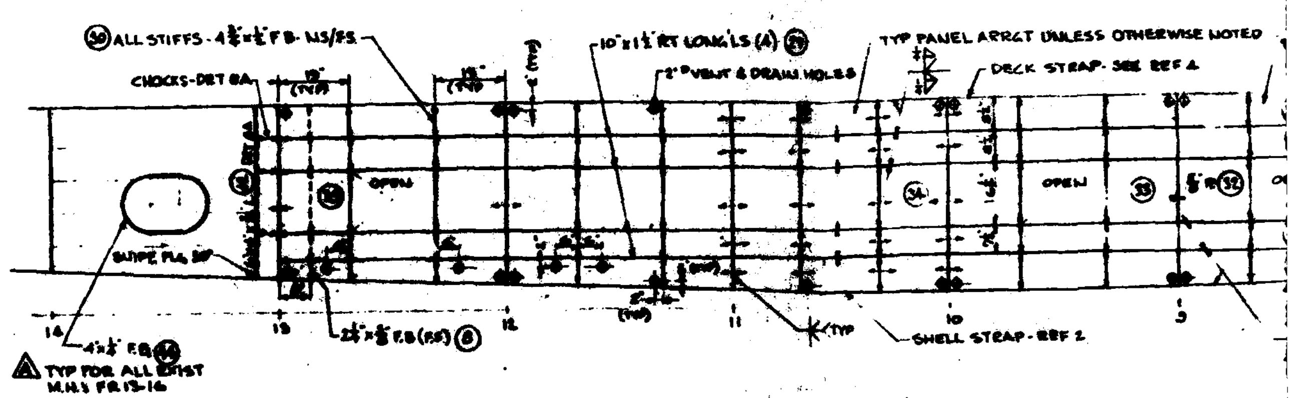
9.2 Hull - The major modification is to the hull and is the reinforcement of the frames and bulkheads and installation of the strut attachment. These are shown on Figures 9-1 through 9-3. Zinc Anodes are to be attached to the hull adjacent to the B/F tank strut and elsewhere to prevent galvanic corrosion.

In addition, the sonar trunk must be modified and foundations are required for the new manifolds and associated components.

9.3 Fluid Systems - The modifications to the fuel, hydraulic, and compressed air systems require only the addition of the subsystems as shown in Figure 6-1 . Minimal rerouting or replacement of existing lines is contemplated.

9.4 Electrical/Electronic Systems - As discussed in Section 7 and diagrammed on Figure 7-1, the steering system requires the major modification due to the addition of the aft rudder. The ship's electrical system must provide power for the pumps, fan and controls associated with the tank installation.

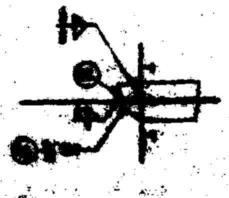
9.5 Outfitting - The platform area and hold area between frames 10 and 12 within the confines of the former sonar trunk require stripping and relocation of existing equipment and joiner installation to provide space for the B/F tank handling and fuel management operation.

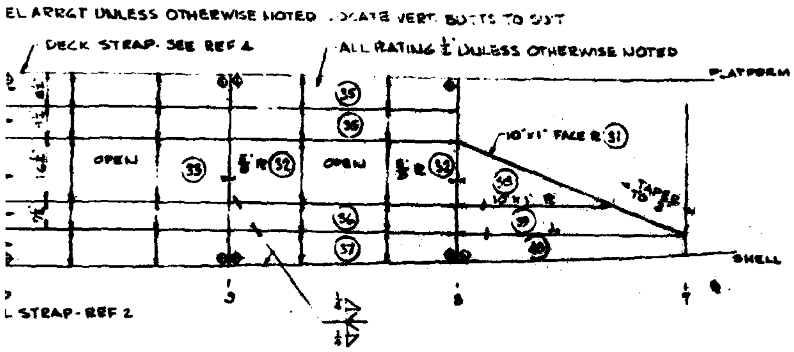


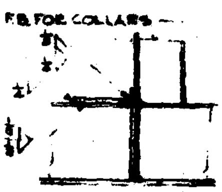
ELEVATION 8A

LONG'L B'HDS 8'-10 3/4" OFF ℄ P/S

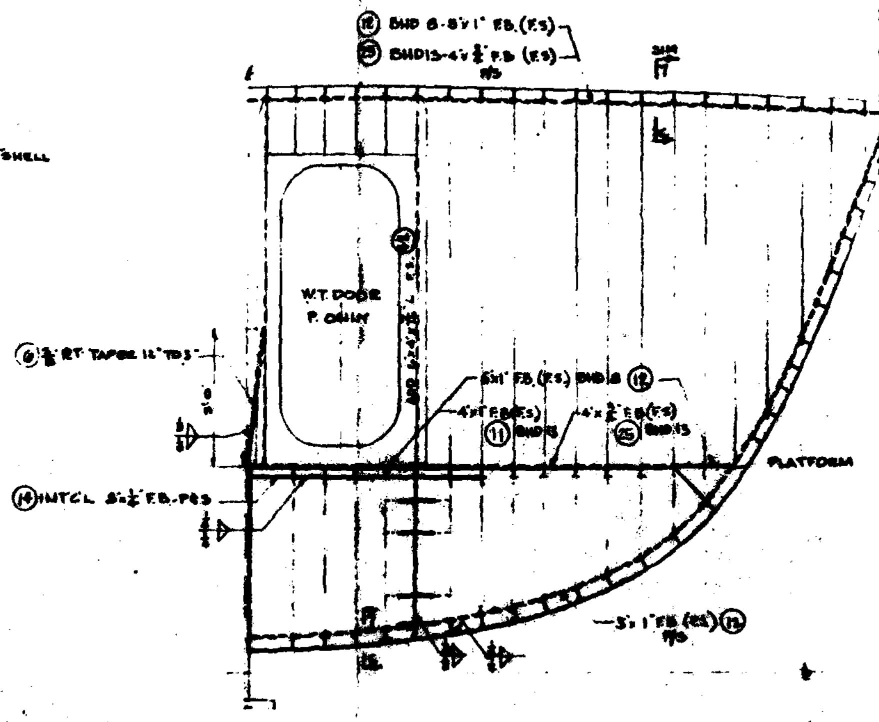
PORT LKG OUTBD SHOWN



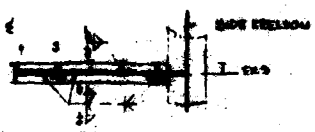




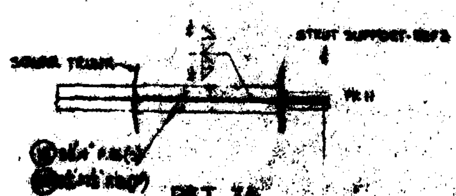
DET 7C
SHELL HEADER
SCALE 3"=1'0"



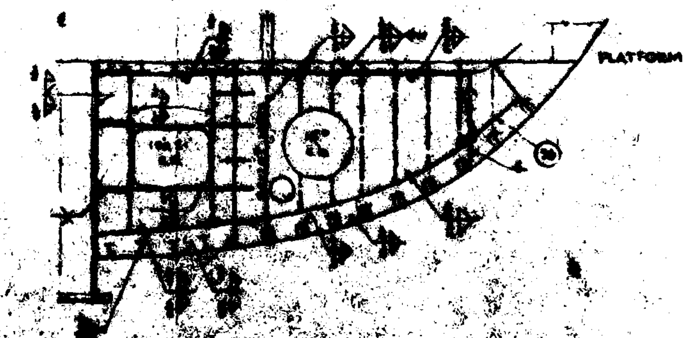
OT/WT BULKHEAD 18
LOOKING AFT
WT BHD FR 8 LKG FWD SIM.
EXCEPT AS NOTED



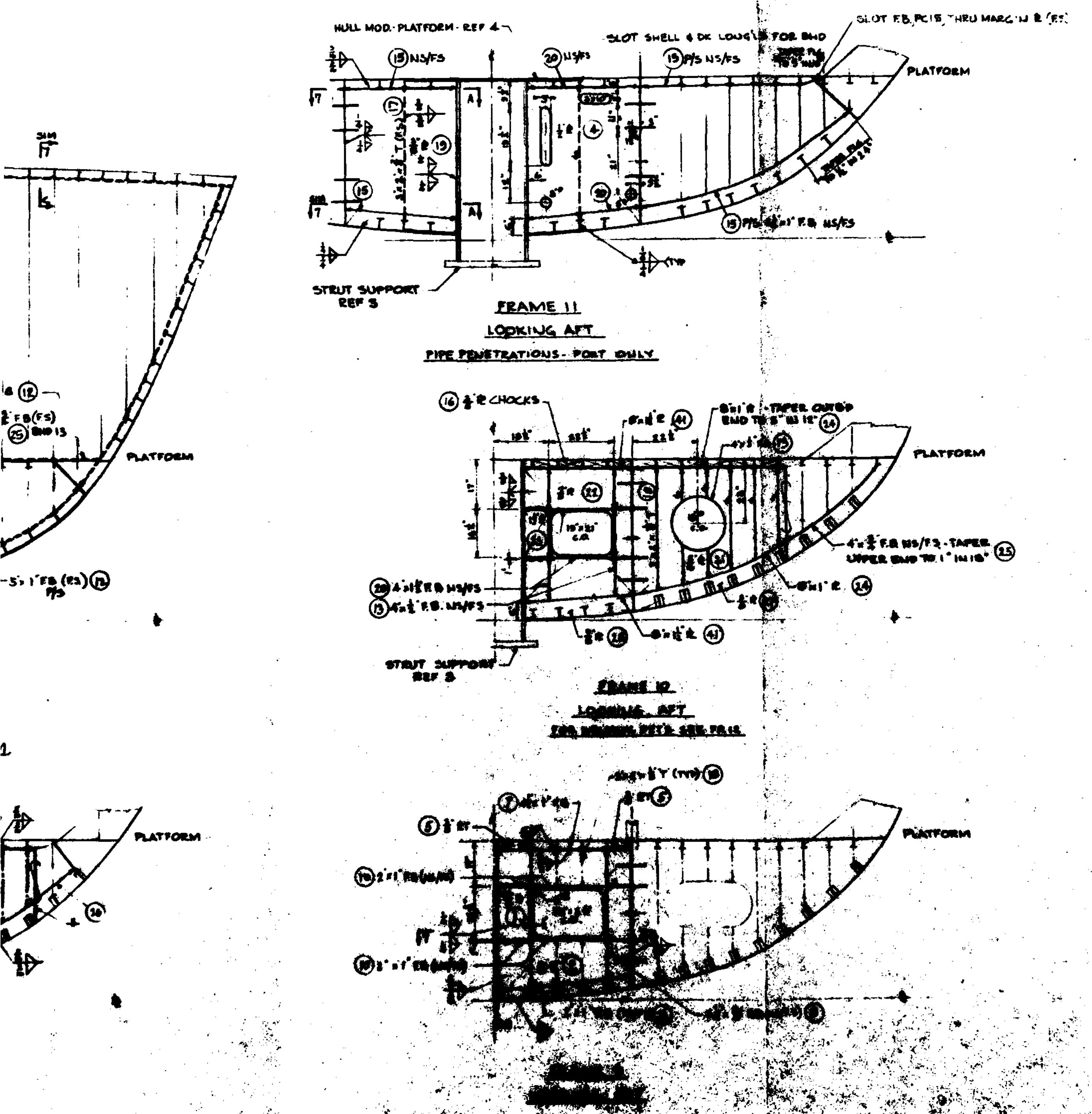
DET 7B
HEADERS- FRAME 9



DET 7A



8A
BRACKETS



1 FABRICAT
0900-
2 WELD SO
3 WELDING
4 FILLER
5 WELD IN
a) VISU
b) AIR
6 STRUCT
7 PORT &

GENERAL NOTES

1. FABRICATION, WELDING, & INSPECTION TO BE IN ACCORDANCE WITH NAVSHIPS 0900-LP-060-4010
2. WELD JOINT DESIGN TO BE IN ACCORDANCE WITH MIL-STD-0022 C (SH)
3. WELDING TO BE EITHER GAS METAL ARC OR GAS TUNGSTEN ARC.
4. FILLER METAL TO BE ALUM ALLOY TYPE 5556 SPEC MIL-E-16053.
5. WELD INSPECTION TO BE AS FOLLOWS:
   a) VISUAL INSPECTION ALL WELDS.
   b) AIR & LEAK DETECTOR SOLUTION - PERIPHERAL WELDS BHD 13
6. STRUCTURE TO BE FINISHED SIMILAR TO ADJACENT STRUCTURE.
7. PORT & STBD SIDES SIMILAR UNLESS NOTED OTHERWISE.

LIST OF MATERIALS

ITEM NO.	QTY REQD	NOMENCLATURE TYPE NUMBER	ITEM NAME	DRAWING OR SPEC NO.	RE...
1	2	AL AL 5456 H116/H117	WEB-FR 9	QQ-A-250-9	[illegible]
2	2		WEB-FR 9		[illegible] R
3			NOT USED		
4	1		WEB-FR 11 PORT		[illegible] R
5	4		CHOCKS		[illegible] R
6	2		STIFFENERS		[illegible] R
7	2		HEADER		1"x4½
8	6		STIFFENER		[illegible] x
9	4		HEADER		1"x
10	12		STIFFENER		1"x
11	1		DECK STRAP		1"x 4
12	120 FT		HEADER		1"x
13	27 FT		HEADER		[illegible] x
14	3		HEADER		[illegible] x
15	65 FT		HEADER		1"x 3
16	40	AL AL 5456 H116/H117	CHOCK	QQ-A-250-9	[illegible] x
17	2	AL AL 5456 H111	STIFFENER	QQ-A-200-7	3"x 2
18	80 FT	AL AL 5456 H111	STIFFENER	QQ-A-200-7	3"x 2
19	1	AL AL 5456 H116/H117	WEB-FR 11 STBD	QQ-A-250-9	[illegible] R
20	14		STIFFENER		1½"x
21	4		WEB-FR 10 & 12		[illegible] R
22	4		WEB-FR 10 & 12		[illegible] R
23	4		WEB-FR 10 & 12		1[illegible] R
24	8		FLANGE-FR 10 & 12		1"x 8
25	70 FT		FLANGE		[illegible] x
26	4		FLANGE-FR 12		[illegible] x
27	4		FRAME WEB		[illegible] R
28	4		FRAME WEB		[illegible] R
29	8		LONG'L STIFF		1½" R
30	175 FT		VERT STIFF		[illegible] x 4
31	20 FT		LONG'L STIFF		1" RT
32	4		BHD WEB		[illegible] R
33	4				[illegible] R
34	2				[illegible] R
35	4				[illegible] R
36	2				[illegible] R
37	2				[illegible] R
38	2				[illegible] R
39	2				[illegible] R
40	2		BHD WEB		[illegible] R
41	8	AL AL 5456 [illegible]	FLANGE	QQ-A-250-9	1½" R
42	2	AL AL 5456 H111	STIFFENER	QQ-A-200-7	6"x 4
43	12	AL AL 5456 [illegible]	KEELSON BKTS	QQ-A-250-9	[illegible] R
44	30 FT	AL AL 5456 [illegible]	M.H. RING	QQ-A-250-9	[illegible] x 4

REFERENCES

NO.	TITLE	NAVSEA DWG NO.	CAS DWG NO.
1	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]

NAVSHIPS

c (SH)

K

59.

3

RE.

LIST OF MATERIALS

Item Name	Drawing or Spec. No.	Remarks
WEB-FR9	QQ-A-250-9	5/8" R - 30"x12"
WEB-FR9		5/8" R - 4'-0"x4'-6"
NOT USED		
WEB-FR 11 PORT		1/2" R - 5'-5"x4'-6"
CHOCKS		3/8" R - 12"x8"
STIFFENERS		3/8" R - 12"x 5'-0"
HEADER		1"x4 1/2" F.B. L=4'-0"
STIFFENER		3/4"x2 1/4" F.B. L=3'-9"
HEADER		1"x 6" F.B. L=4'-0"
STIFFENER		1"x2" F.B. L=3'-7"
DECK STRAP		1"x 4" F.B. L=8'-0"
HEADER		1" x5" F.B. TO CUT
HEADER		3/4"x 4" F.B. TO CUT
HEADER		3/4"x5" F.B. L= 5'-6" TO CUT
HEADER		1"x 3 1/2" F.B. TO CUT
CHOCK	QQ-A-250-9	3/8"x2 1/2" F.B. L=9"
STIFFENER	QQ-A-200-7	3"x2"x 3/8"T L=4'-0"
STIFFENER	QQ-A-200-7	3"x2"x 3/8"T TO CUT
WEB-FR 11 STBD	QQ-A-250-9	3/8" R 5'-3"x 4'-6"
STIFFENER		1 1/2"x 4" F.B. L=3'-5"
WEB-FR 10 & 12		3/4" R - 4'-6"x 5'-8"
WEB-FR 10 & 12		3/8" R 4'-0"x 3'-5"
WEB-FR 10 & 12		1 1/2" R - 18 1/2"x10"
FLANGE-FR 10 & 12		1"x 8" R L=5'-6"
FLANGE		3/4"x4" F.B. TO CUT
FLANGE-FR 12		3/4"x4" F.B. L=18"
FRAME WEB		3/8" RT - 12"x 8'-0"
FRAME WEB		3/8" RT - 9"x 3'-3"
LONG'L STIFF		1 1/2" RT 10"x 25'-0"
VERT STIFF		1/2"x4 1/2" F.B. TO CUT
LONG'L STIFF		1" RT - 10"x 30'-0" TO CUT
END WEB		5/8" RT - 16 1/2"x 13"
		1/2" RT - 16 1/2"x19"
		1/2" RT - 16 1/2"x 13'-6"
		1/2" RT - 8 1/2"x 25'-0"
		1/2" RT - 7 1/2"x 25'-0"
		1/2" RT - 9"x 25'-0"
		1/2" RT 18"x 8'-6"
		1/2" RT 7 1/2"x 9'-0"
END WEB		1/2" RT 7"x 8'-0"
FLANGE	QQ-A-250-9	1 1/2" RT 8"x 3'-3"
STIFFENER	QQ-A-200-7	6"x4"x 3/8" L L=13'-0"
KEELSON BKTS	QQ-A-250-9	3/8" RT 14"x9"
RING	QQ-A-250-9	1/4"x4" F.B. TO CUT

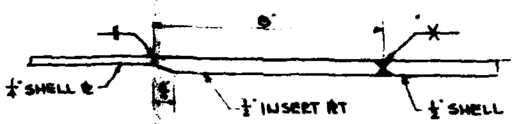
REVISIONS

Zone	Ltr	Description	Appd	Date
[illegible]	A	[illegible] TO SUIT [illegible]	[illegible]	[illegible]

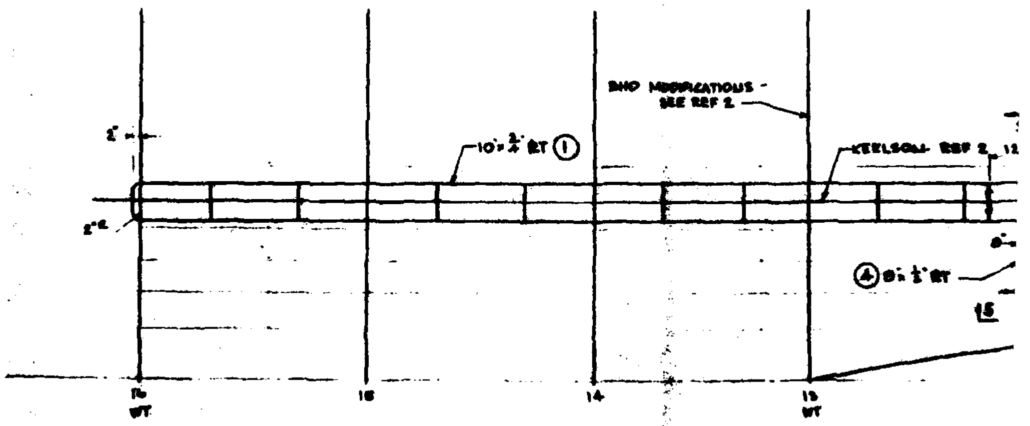
REFERENCES

	NAVSEA DWG NO.	GAC DWG NO.
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

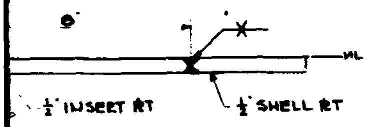
FIGURE 9-1



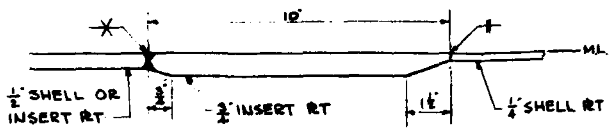
DETAIL 5A
TYP WELDING OF TRANS.
INSERT PLATES
SCALE: 6"=1'-0"



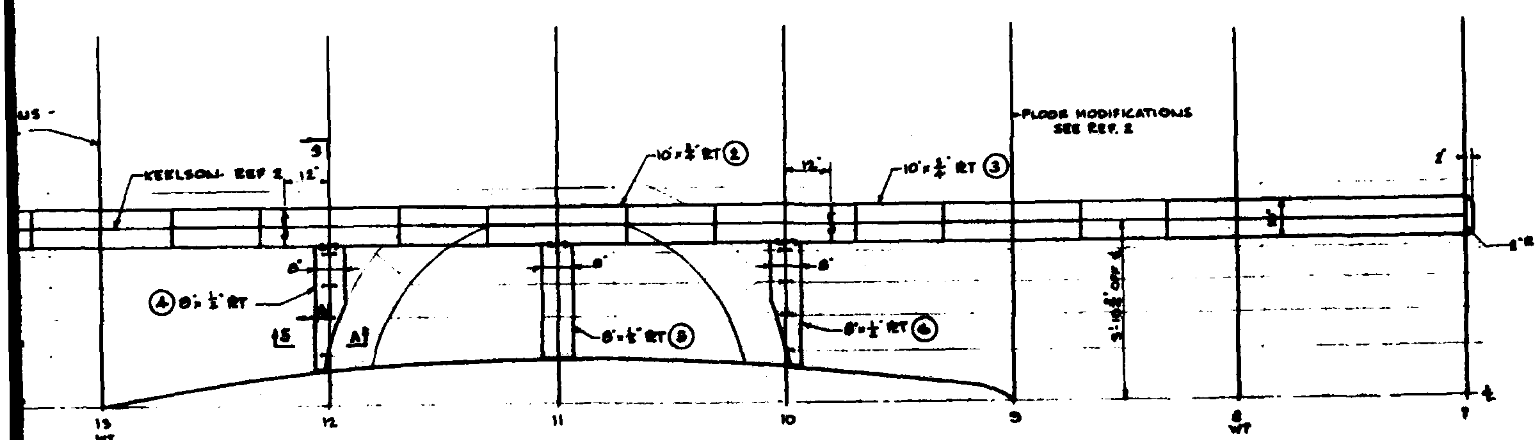
1 FA
WI
2 W
3 W
4 FI
5 WI
6 PI



DETAIL 5A
WELDING OF TRANS.
INSERT PLATES
SCALE: 6"=1'-0"



DETAIL 3A
TYP. WELDING OF LONG'L
INSERT PLATES
SCALE: 6"=1'-0"



PLAN - BOTTOM SHELL
SCALE: 3/8"=1'-0"

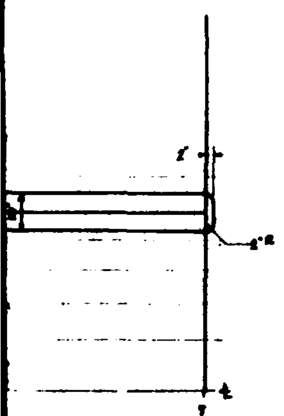
2

GENERAL NOTES

1. FABRICATION, WELDING & INSPECTION TO BE IN ACCORDANCE WITH NAVSHIPS 0900-LP-060-4010
2. WELD JOINT DESIGN TO BE IN ACCORDANCE WITH MIL-STD-0022 C (SH).
3. WELDING TO BE EITHER GAS METAL ARC OR GAS TUNGSTEN ARC.
4. FILLER MATERIAL TO BE ALUM ALLOY TYPE 5556 SPEC MIL-E-16053
5. WELD INSPECTION TO BE AS FOLLOWS:
   a) VISUAL INSPECTION ALL WELDS.
   b) AIR & LEAK DETECTOR SOLUTION ALL WELDS.
   c) DYE PENETRANT ALL BUTT WELDS BETWEEN INSERT PTS.
6. PAINT TO MATCH SURROUNDING STRUCTURE.

LIST OF MATERIALS

ITEM NO	QTY REQD	NOMENCLATURE TYPE-NUMBER	NOMENCLATURE ITEM NAME	DRAWING OR SPEC NO.	REMARKS
1	2	ALUM AL 5456	INSERT PT-LONG'L	QQ-A-250-9	¾" PT-10" x 20'-0"
2	2				¾" PT-10" x 12'-6"
3	2		LONG'L		¾" PT-10" x 16'-0"
4	2		-TRANS		½" PT-8" x 3'-0"
5	2				½" PT-8" x 2'-9"
6	2	ALUM AL 5456	INSERT PT TRANS	QQ-A-250-9	½" PT-8" x 5'-0"



REFERENCES

NO	TITLE	NAVSEA DWG NO.	GAC DWG NO.
1	SHIP MODIFICATION-REMOVALS	802-5884534	H163-C0-10001
2	SHIP MODIFICATION-FRAMES [illegible]	802-5884535	H163-C0-[illegible]
3			

...N TO BE IN ACCORDANCE
...
...NCE WITH MIL-STD-0022C (SH).
...RC OR GAS TUNGSTEN ARC.
...YPE 5556 SPEC MIL-E-16053
...S:

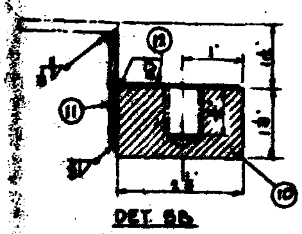
... ALL WELDS.
... BETWEEN INSERT RTS.
...UCTURE.

LIST OF MATERIALS			
ITEM NO	NOMENCLATURE — ITEM NAME	DRAWING OR SPEC NO	REMARKS
1	INSERT RT - LONG'L	QQ-A-250-5	⅜" RT - 10' x 20'-0"
2	⋮	⋮	⅜" RT - 10' x 12'-6"
3	LONG'L	⋮	⅜" RT - 10' x 15'-0"
4	- TRANS	⋮	½" RT - 8' x 3'-0"
5	⋮	⋮	½" RT - 8' x 2'-9"
6	INSERT RT TRANS	QQ-A-250-5	½" RT - 8' x 3'-0"

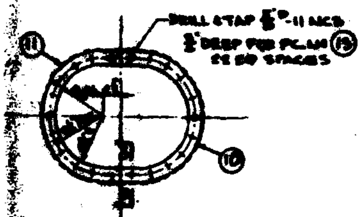
REVISIONS				
ZONE	LTR	DESCRIPTION	APP'D	DATE

[illegible] REFERENCES			
NO	[illegible]	NAVSEA DWG NO	GAC DWG NO.
1	SH [illegible]	[illegible] 5754534	M69-CD-10001
2	SH [illegible]	[illegible]	M69-CD-[illegible]
3			

FIGURE 9-2

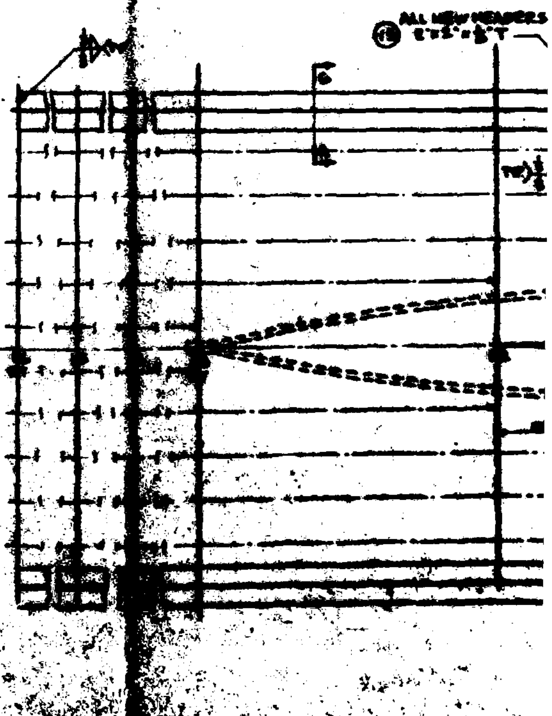


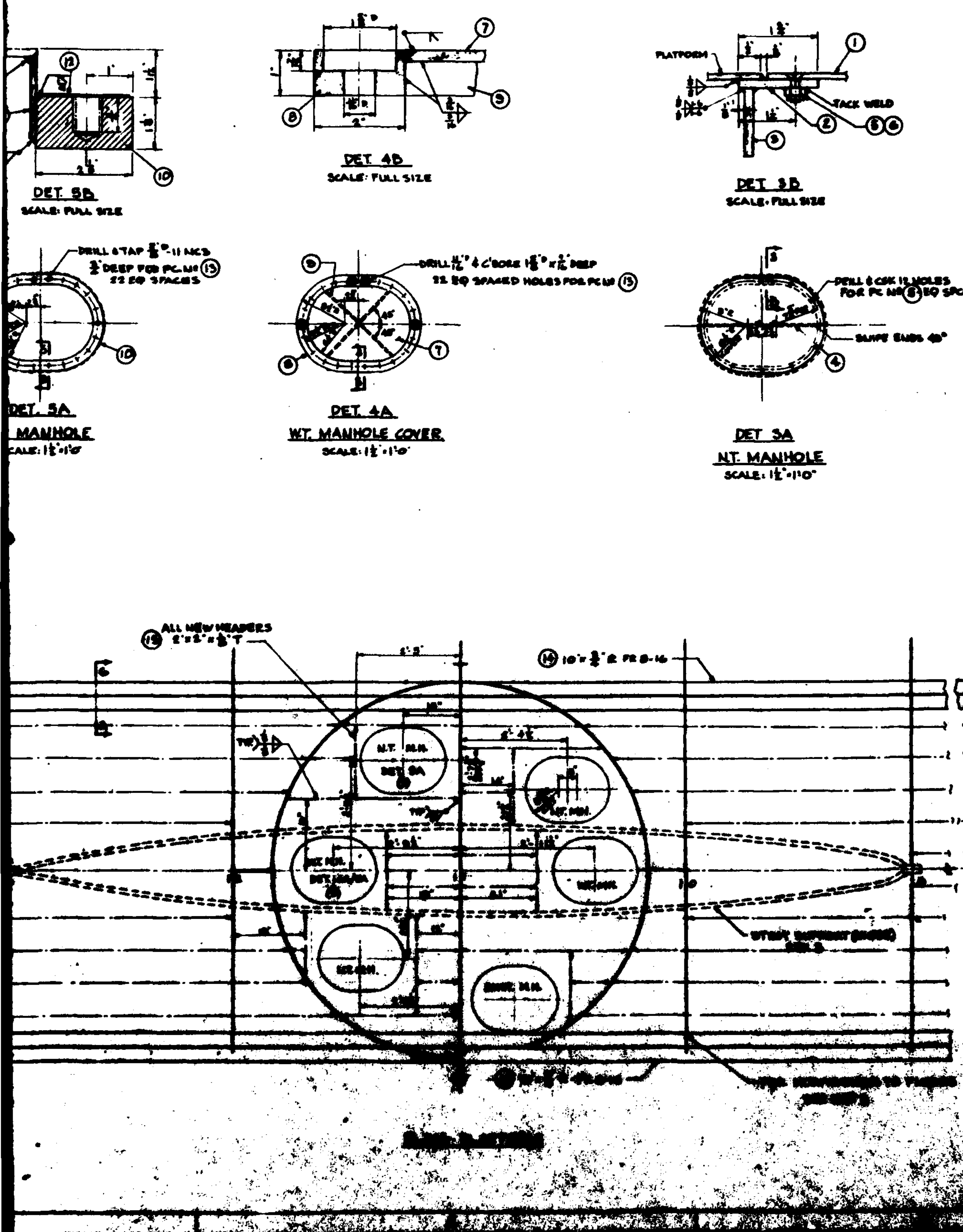
DET. 5B
SCALE: FULL SIZE



DET. 5A
W.T. MANHOLE
SCALE: 1½"=1'

DET. 4A





GENERAL NOTES

1. FABRICATION, WELDING, & INSPECTI... ACCORDANCE WITH NAVSHIPS ...
2. WELD JOINT DESIGN TO BE IN ACC... MIL-STD-...
3. WELDING TO BE EITHER GAS METAL ... TUNGSTEN ARC. - FILLER MAT'L TO BE ... TYPE ... SPEC MIL-E-...
4. VISUALLY INSPECT ALL WELDS. AIR & LEAK DETECTOR TEST ALL WELDS WITHIN STRUT CONTOUR.
5. PLATING OVER STRUT SUPPORT TO ... CONTOURS OF SIDE PLATING.

GENERAL NOTES

[illegible]RICATION, WELDING, & INSPECTION TO BE IN [illegible]CORDANCE WITH NAVSHIPS 0900-LP-060-4010

[illegible]LD JOINT DESIGN TO BE IN ACCORDANCE WITH [illegible]-STD-0022C (SH)

[illegible]LDING TO BE EITHER GAS METAL ARC OR GAS [illegible]NGSTEN ARC. - FILLER MAT'L TO BE ALUM ALLOY [illegible] 5556 SPEC MIL-E-16053

[illegible]ALLY INSPECT ALL WELDS

[illegible] & LEAK DETECTOR TEST ALL EXTERNAL [illegible]LDS WITHIN STRUT CONTOUR.

[illegible]TING OVER STRUT SUPPORT TO BE WT WITHIN [illegible]NTOURS OF SIDE PLATING

LIST OF MATERIALS

ITEM NO.	QTY	NOMENCLATURE: MIL-NUMBER	NOMENCLATURE: ITEM NAME	DRAWING OR SPEC NO.	REMARKS
1	[illegible]	AL.ALLOY 5086 [illegible]	COVER	QQ-A-250-[illegible]	[illegible] 17"x22"
2	[illegible]		COVER SILL		[illegible]
3	[illegible]		STIFFENER RING		[illegible]
4	[illegible]	AL.ALLOY 5086 [illegible]	COVER STIFF.	QQ-A-250-[illegible]	[illegible] L=19"
5	[illegible]	CRES	F.H. HEX SOCKET SCREW		[illegible] 10-24 NC [illegible]
6	[illegible]	ALUM	[illegible] FLEXLOC [illegible]	P77FA-1024	
7	2	AL.ALLOY 5086 [illegible]	COVER	QQ-A-250-[illegible]	[illegible] 13"x16"
8	2		COVER RING		[illegible]
9	[illegible]		STIFFENERS		[illegible] TO SUIT
10	[illegible]		LOWER RING		[illegible]
11	[illegible]	AL.ALLOY 5086 [illegible]	SIDE RING	QQ-A-250-[illegible]	[illegible]
12	2	[illegible] RUBBER	GASKET	MIL-G-[illegible]	[illegible] 17"x22"
13	[illegible]	CRES	BOLT-HEX HD		[illegible]
14	[illegible]	AL.ALLOY 5086 [illegible]	DECK STRAP	QQ-A-250-[illegible]	[illegible]
15	[illegible]	AL.AL [illegible]	HEADERS	QQ-A-200-7	[illegible] T

REVISIONS

[illegible]	[illegible]	DESCRIPTION	APPD	[illegible]

FIGURE 9-3

NOTES

, & INSPECTION TO BE IN
SHIPS 0900-LP-060-4010
) BE IN ACCORDANCE WITH

GAS METAL ARC OR GAS
MAT'L TO BE ALUM ALLOY
-E-16053
VELDS
R TEST ALL EXTERNAL
CONTOUR.
SUPPORT TO BE WT WITHIN
ATING

LIST OF MATERIALS

ITEM NO	NOMENCLATURE: MATERIAL	NOMENCLATURE: ITEM NAME	DRAWING OR SPEC NO.	REMARKS
1	[illegible]	COVER	QQ-A-250-9	[illegible]" R - 17"x22"
2	[illegible]	COVER SILL	[illegible]	[illegible]" R - 16"x23"
3	[illegible]	STIFFENER RING	[illegible]	1½"x[illegible]" FB L=8'-5"
4	[illegible]	COVER STIFF.	QQ-A-250-9	1½"x[illegible]" FB L=19"
5	[illegible]	F.H. HEX SOCKET SCREW		L=[illegible]" #10-24 NC 2
6	[illegible]	NUT SPG FLEXLOC [illegible]	P77FA-1064	
7	[illegible]	COVER	QQ-A-250-9	[illegible]" R - 15"x18"
8	[illegible]	COVER RING	[illegible]	1" R 17"x22"
9	[illegible]	STIFFENERS	[illegible]	[illegible]"x[illegible]" FB TO CUT
10	[illegible]	LOWER RING	[illegible]	1½" R - 1[illegible]"x21½"
11	[illegible]	SIDE RING	QQ-A-250-9	1½"x[illegible]" FB L=8'-6"
12	[illegible]	GASKET	MIL-G-23985	[illegible] THK - 17"x22"
13	[illegible]	BOLT - HEX HD		[illegible]" 11 NC 3 L=1[illegible]"
14	[illegible]	DECK STRAP	QQ-A-250-9	[illegible]" R 10"x 40'-0"
15	[illegible]	HEADERS	QQ-A-200-7	2"x2"x[illegible]" T

REVISIONS

SYM	ZONE	DESCRIPTION	APP'D	DATE

[illegible]	[illegible]	[illegible]	[illegible]
1	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]

FIGURE 9-3

SECTION 10

RECOMMENDATIONS

10.0 The contents of this report should indicate that the concept and physical fabrication of the B/F tank would be entirely feasible. However, as a result of the detail design investigation, it is believed that there are a number of uncertainties remaining in the total concept of the program which should be resolved prior to proceeding to a construction/ship alt phase.

10.1 Of primary concern is the predicted performance of the craft inasmuch as the estimated displacement and dynamic lift values have increased considerably during the detail design phase.

10.2 The transmission analysis being conducted by HYSTU should be investigated for its impact on the M169 design.

10.3 It must be ascertained that it is physically possible to install the B/F tank to the hull in dry dock or on shore-based high stands.

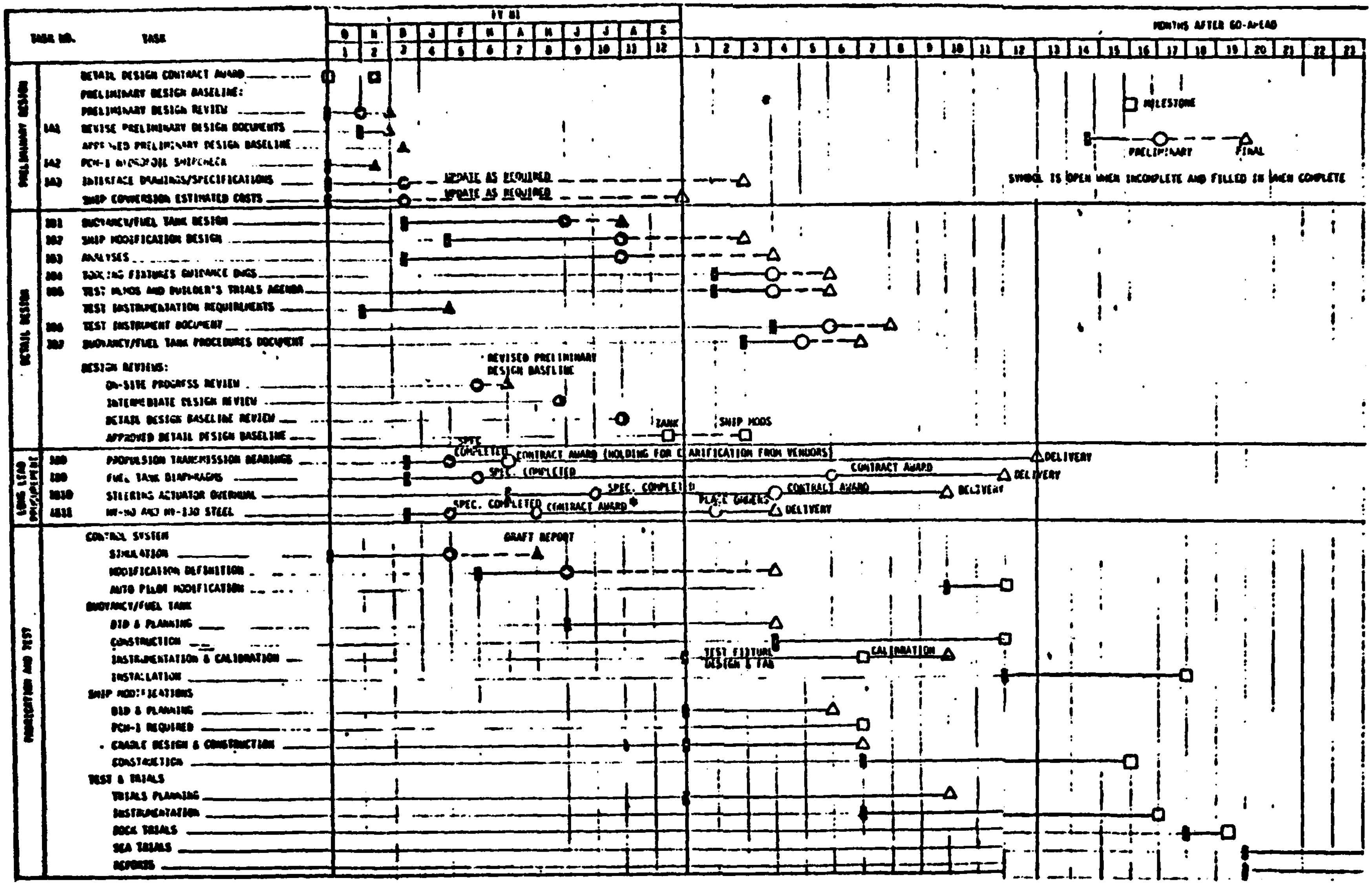
SECTION 11

SCHEDULE

11.0 Proposed DTNSRDC schedule for the implementation of the Buoyancy/Fuel Tank installation on the PCH-1 are shown on Figure 11-1, and have been extended to indicate the anticipated effort from detail design through sea trials.

11.1 Not specifically identified on the schedule, Figure 11-1 is the fabrication of those items of hydrodynamic form for which Grumman has unique capabilities, and for which it would entertain an invitation to submit a construction quote. The items considered for Grumman fabrication would be the composite material nose and tail cones, the rudder and stabilizer fins and the HY100 steel strut.

PCH-1 EXTENDED PERI... L HYDROFOIL FEASIBILITY DEMONSTRATION SCHEDULE 22 SEPTEMBER 1981



* PURCHASE ORDER RETRACTED DUE TO FUNDING UNCERTAINTY, 17 JUNE 1981

SECTION 12

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APPENDIX A

TO

GRUMMAN REPORT NO. MAR 1373-921-1

PCH-1 'HIGH POINT' BASELINE DESIGN REPORT

OF

EXTENDED PERFORMANCE HYDROFOIL PROGRAM

PCH-1 FEASIBILITY DEMONSTRATOR

BEARING LIFE CALCULATIONS

December 15, 1980

DESIGN NO.	SUBJECT		WBS
M 169	PCH-1 "HYBRID" BEARING LIFE CALCULATIONS		
ANALYST	CHECKER	ANALYSIS DATE	PAGE NO.
G. MILLER		9/14/79	A1 OF 26

BEARING LIFE CALCULATIONS - UPPER GEARBOX

DETERMINE THE B-10 LIFE OF THE BEARINGS IN THE PORT + STBD UPPER GEARBOXES.

ASSUMPTIONS:

1. LOADS TO BE ABSORBED BY BEARINGS ARE ADEQUATELY REPRESENTED IN TABLE 1.

OPERATING CONDITION	TIME %	ENGINE HP.	INPUT SHAFT RPM	INPUT SHAFT TORQUE lb-in.
TAKE OFF + HIGH SPEED FOIL BORNE	10	4110	4200	61,700
CRUISE - MAX RANGE	70	3600	3859	58,800
IDLING	20	30	673	2,810

TABLE 1.

NOTE: THE LOADS TO BE ABSORBED BY THE BEARINGS WERE REVISED TO REFLECT THE INCREASED THRUST REQUIRED WITH THE BUOYANCY/FUEL TANK INSTALLED.

2. BALL BEARINGS REACT THRUST LOADS ONLY.

GRUMMAN AEROSPACE CORPORATION

MARINE DESIGN ANALYSIS

DESIGN NO.	SUBJECT			WBS
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			9-14-79	A2

UPPER GEARBOX

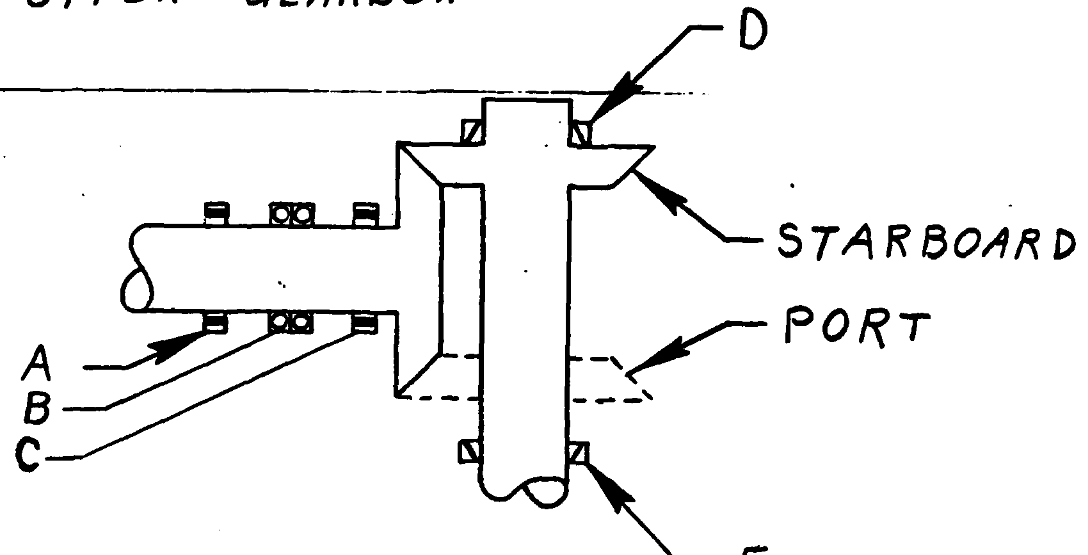

FIG. 1

A - SKF N319 MC/C3 ; C = 53,200 lbs.

B - SKF 7321 MC/G ; C = 58,400 lbs.
X_2 = 0.59 Y_2 = 1.01

C - SKF N324 MC/C3 ; C = 93,400 lbs.

D - TIMKEN 936/932 ; BRR = 22,400 lbs, K = 1.79

E - TIMKEN 938/932 ; BRR = 22,400 lbs, K = 1.79

24300 SEE NOTE PG. 11.

BEARINGS LISTED ARE IN ACCORDANCE WITH ref 1 AND 3.

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REPORT

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DESIGN NO.	SUBJECT		WBS
M-169	PCH-1 "HYBRID" BEARING LIFE CALCULATIONS		
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DETERMINE MEAN TORQUES

a) FOR BALL BEARINGS

$$T_m = \left[\frac{T_1^3 N_1 + T_2^3 N_2 + T_3^3 N_3}{N_1 + N_2 + N_3}\right]^{1/3}$$

T_1 = TAKE OFF + HIGH SPEED FOILBORNE TORQUE = 61,700 lb in.
N_1 = TAKE OFF + HIGH SPEED FOILBORNE RPM = 4200
T_2 = CRUISE TORQUE = 58,800 = .953 T_1
N_2 = CRUISE SPEED = 3,857 = .918 N_1
T_3 = IDLE TORQUE = 2,810 = .046 T_1
N_3 = IDLE SPEED = 673 = .160 N_1

$$T_m = T_1\left[\frac{(1)^3(1) + (.953)^3(.918) + (.046)^3(.16)}{1 + .918 + .16}\right]^{1/3}$$

$$T_m = T_1\left[\frac{1 + .79455 + .00002}{2.078}\right]^{1/3}$$

$$T_m = T_1\left[\frac{1.79457}{2.078}\right]^{1/3} = T_1\left[.8636\right]^{1/3}$$

$$T_m = .952\ T_1 = (.952)(61700)$$

$$\underline{T_m = 58,740 \text{ lb in.}}$$

$$RPM_m = (.1)(4200) + (.7)(3859) + (.2)(673)$$

$$\underline{RPM_m = 3256}$$

GRUMMAN AEROSPACE CORPORATION

MARINE DESIGN ANALYSIS

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b) FOR ROLLER BEARINGS

$$T_m = \left[\frac{T_1^{10/3}N_1 + T_2^{10/3}N_2 + T_3^{10/3}N_3}{N_1 + N_2 + N_3}\right]^{3/10}$$

$$T_m = T_1\left[\frac{(1)(1) + (.953)^{10/3}(.918) + (.046)^{10/3}(.16)}{1 + .918 + .16}\right]^{3/10}$$

$$T_m = T_1\left[\frac{1 + .7819 + .0000056}{2.078}\right]^{3/10}$$

$$T_m = T_1\left[\frac{1.7819}{2.078}\right]^{3/10} = T_1\left[.8575\right]^{3/10}$$

$$T_m = .955\,T_1 = (.955)(61700)$$

$$\underline{T_m = 58925}$$

FOR CALCULATIONS USE:

$T_m = 58925$

$RPM_m = 3256$

GEAR LOADS

NOTE: LOAD RELATIONSHIPS WERE OBTAINED FROM ref #3. THE GLEASON DIMENSION SHEET WAS NOT AVAILABLE TO CHECK RELATIONSHIPS.

TANGENTAL FORCE $TF = 1/3.45\,T_m \therefore TF = 17{,}080$ lbs.

AXIAL FORCE $T_{TF} = 0.189\,T_m \therefore T_{TF} = 11{,}137$ lbs.

GRUMMAN AEROSPACE CORPORATION

MARINE DESIGN ANALYSIS

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SEPARATING FORCE $S_{TF} = 0.071\ T_m \therefore S_{TF} = 4184$ lb.

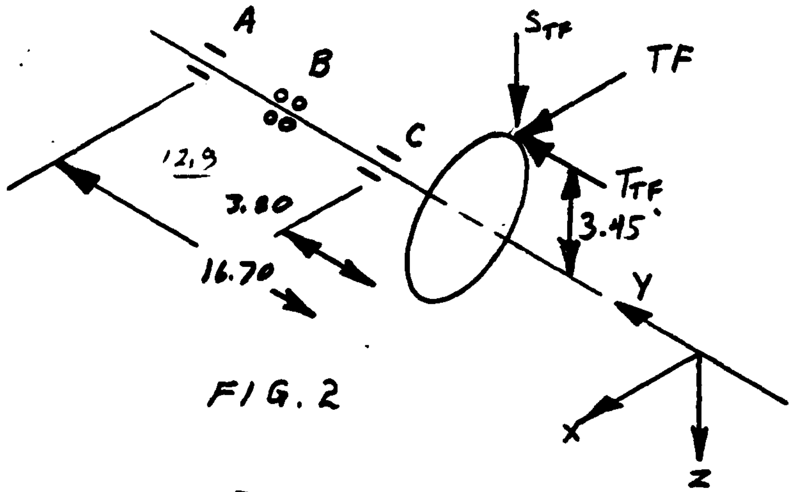

FIG. 2

$$\Sigma F_y : 0 = T_{TF} - F_{BY}$$

$\therefore F_{BY} = 11,137$ lbs.

$$P = (Y_2)(F_{BY}) = (1.01)(11,137) = 11248$$

$P = 11248$ lb.

$$\frac{C}{P} = \frac{58\,400}{11248} = 5.19$$

FOR BALL BEARINGS $\frac{C}{P}$ ƒ5.19 $\Rightarrow 140 \cdot 10^6$ REVOLUTIONS.

@ REV_m $\frac{140 \cdot 10^6 \text{ REV} \cdot \text{min} \quad \text{HR}}{3256 \text{ REV} \quad 60 \text{ min}}$

B-10 LIFE FOR BEARING B = 716 HOURS

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GRUMMAN AEROSPACE CORPORATION
MARINE DESIGN ANALYSIS

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$\Sigma M_{YZ_A} = 0 \qquad M \downarrow +$

$\Sigma M_{YZ_A} = -(11137)(3.45) + (4184)(16.7) + F_{CZ}(12.9)$

$F_{CZ} = -2438 \text{ lb} = 2438 \uparrow$

$\Sigma M_{YZ_C} = 0$

$\Sigma M_{YZ_C} = -(11137)(3.45) + (4184)(3.8) - F_{AZ}(12.9)$

$F_{AZ} = -1746 = 1746 \uparrow$

$\Sigma F_Z = 0 = F_{AZ} + F_{CZ} + S_{TF}$

$0 = -1746 - 2438 + 4184$ ✓

$\Sigma M_{XY_A} = 0 = +(F_{CX})(12.9) + (17080)(16.7)$

$F_{CX} = -22111 = 22111$

$\Sigma F_{XY_C} = 0 = F_{AX}(12.9) + (17080)(3.8)$

$F_{AX} = 5031 = 5031$

$\Sigma F_X = 0 = F_{CX} + F_{AX} + TF$

$0 = -2211 + 5031 + 17080$ ✓

RESULTANT FORCE

$F_{RC} = \sqrt{F_{CX}^2 + F_{CZ}^2} = \sqrt{(-22111)^2 + (2438)^2}$

$F_{RC} = 22245 \text{ lbs.}$

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GRUMMAN AEROSPACE CORPORATION

MARINE DESIGN ANALYSIS

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M169	PCH-1 HYBRID BEARING LIFE CALC			
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$$F_{RA} = \sqrt{F_{AY}^2 + F_{AZ}^2} = \sqrt{(5031)^2 + (1746)^2}$$

$F_{RA} = 5325$ lbs.

FOR BEARING A

$$\frac{C}{P} = \frac{53200}{5325} = 10 \Rightarrow 2150 \cdot 10^6 \text{ rev.}$$

$$2150 \cdot 10^6 \text{ REV} \cdot \frac{\text{MIN}}{3256 \text{ REV}} \cdot \frac{\text{HR}}{60 \text{ MIN}}$$

B-10 LIFE FOR BEARING A = 11,000 HOURS

FOR BEARING C

$$\frac{C}{P} = \frac{93400}{22245} = 4.2 \Rightarrow 110 \cdot 10^6 \text{ rev}$$

$$110 \cdot 10^6 \text{ REV} \cdot \frac{\text{MIN}}{3256 \text{ REV}} \cdot \frac{\text{HR}}{60 \text{ min}}$$

B-10 LIFE FOR BEARING C = 563 HOURS

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GRUMMAN AEROSPACE CORPORATION

MARINE DESIGN ANALYSIS

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M-169	PCH-1 HYBRID BEARING LIFE CALC			
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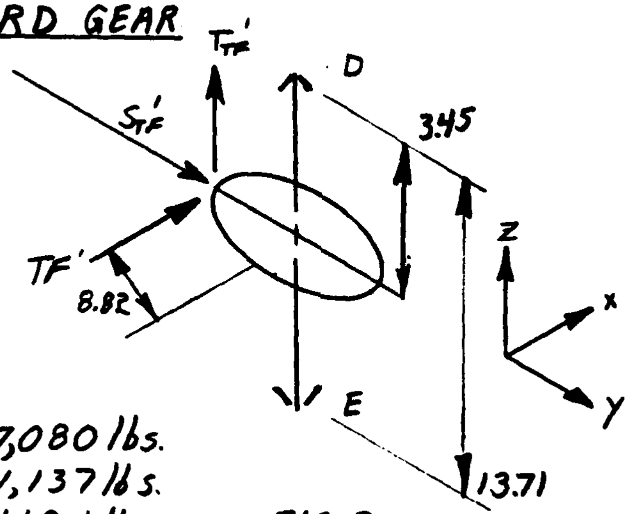
STARBOARD GEAR



$TF = TF' = 17{,}080$ lbs.
$T_{TF} = S'_{TF} = 11{,}137$ lbs.
$S_{TF} = T'_{TF} = 4{,}184$ lbs.

FIG. 3.

$$\Sigma F_z = 0 = T'_{TF} + F_{DZ}$$

$$\therefore \; F_{DZ} = 4{,}184 \text{ lbs}$$

$$\left(\Sigma M_E\right)_{ZY} = 0 = F_{DY}(13.71) + S'_{TF}(10.26) + T'_{TF}(8.82)$$

$$0 = F_{DY}(13.71) + (11137)(10.26) + (4184)(8.82)$$

$$F_{DY} = -11026 \text{ lbs} = 11026 \leftarrow$$

$$\left(\Sigma M_D\right)_{ZY} = 0 = F_{EY}(13.71) - S'_{TF}(3.45) + T'_{TF}(8.82)$$

$$0 = -F_{EY}(13.71) - (11137)(3.45) + (4184)(8.82)$$

$$F_{EY} = -111 \text{ lbs.}$$

$$\Sigma F_y = 0 = +11137 - 11026 - 111$$

GRUMMAN AEROSPACE CORPORATION

MARINE DESIGN ANALYSIS

DESIGN NO.	SUBJECT		WBS
M-169	PCH-1 HYBRID BEARING LIFE CALC.		
ANALYST: G. MILLER	CHECKER:	ANALYSIS DATE: 9/17/79	PAGE NO.: A9

$$\left(\Sigma M_E\right)_{XY} = 0 = F_{DX}(13.71) + TF'(10.26)$$

$$F_{DX} = -\frac{(17080)(10.26)}{13.71} = -12782 \text{ lbs.}$$

$$\underline{F_{DX} = -12782 \text{ lbs.}}$$

$$\left(\Sigma M_D\right)_{XY} = 0 = F_{EX}(13.71) - TF'(3.45)$$

$$F_{EX} = \frac{(17080)(3.45)}{13.71} =$$

$$\underline{F_{EX} = -4298}$$

$$\Sigma F_X = 0 = F_{EX} + F_{DX} + TF'$$

$$0 = -4298 - 12782 + 17080 \checkmark$$

RESULTANT FORCES

$$F_{DR} = \left[\overset{F_{DY}}{-12782^2} + \overset{F_{DY}}{11026^2}\right]^{1/2}$$

$$\underline{F_{DR} = 16880 \text{ lbs.}}$$

$$F_{ER} = \left[-4298^2 + -111^2\right]^{1/2}$$

$$\underline{F_{ER} = 4300 \text{ lbs.}}$$

FOR TIMKEN BEARINGS - USE TIMKEN FORMULAS:

$$\frac{.47\,R_A}{K_A} \overset{?}{\gtrless} \frac{.47\,R_B}{K_B}$$

WHEN $R_A = F_{DR} = 16880$
$R_B = F_{ER} = 4300$
$K_A = K_B = 1.79$

$$(.47)(16880) > (.47)(4300)$$

$\therefore$ FOR EQUIVALENT RADIAL LOAD (RE)

$$RE_A = .053\,R_A + .47\,R_B + K_A T_A$$

$$RE_B = R_B$$

$RE_A = RE_D$
$RE_B = RE_E$
$T_A = F_{DZ} = 4184$

$$RE_D = (.053)(16{,}880) + (.47)(4300) + (1.79)(4{,}184)$$

RE_D 18,460 lbs.

$RE_E = R_E = F_{ER} = 4{,}300$ lbs.

MEAN RPM $= \frac{20}{51} \cdot \underline{3256} = 1277$

SPEED/LIFE FACTOR

@ 1277 RPM SF = .7548 from $\left(\frac{500}{SPEED}\right)^{.3}$

GRUMMAN AEROSPACE CORPORATION

MARINE DESIGN ANALYSIS

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M-169	PCH-1 HYBRID BEARING LIFE CALC		
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THE BEARING LIFE BEARING D. STBD.

$$L_{10} = \left(\frac{C(90) \times SF}{P}\right)^{3.3333} \times 3000 \text{ HOURS}$$

$P = RE_D = 18,460$ (DYNAMIC EQUIVALENT RADIAL LOAD)
$C(90) = 22\,400$ (BASIC DYNAMIC RADIAL LOAD RATING)
$SF = .7548$ (SPEED/LIFE FACTOR)

~~B10 LIFE OF BEARING D = 2,238 HOURS~~ } SEE NOTE

NOTE: THE BASIC DYNAMIC RADIAL LOAD RATING OF 22400 TAKEN FROM REF. 3 DOES NOT AGREE WITH CATALOG RATING OF 24300. USING THE CATALOG RATING OF 24300 RESULTS IN AN B_{10} D = 2936 HOURS.

THE BEARING LIFE BEARING E. STBD.

$$L_{10_E} = \left(\frac{C(90) \times SF}{P}\right)^{10/3} \cdot 3000 = \left(\frac{24300 \;\; .7548}{4300}\right)^{10/3} 3000$$

B-10 LIFE OF BEARING E = 377,600 HOURS

GRUMMAN AEROSPACE CORPORATION
MARINE DESIGN ANALYSIS

DESIGN NO.	SUBJECT			WBS
M169	PCH-1 HYBRID BEARING LIFE CALC.			
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G. MILLER.			9/18/79	A12

PORT UPPER GEARBOX.

PINION BEARINGS - SAME AS STARBOARD.

GEAR BEARINGS

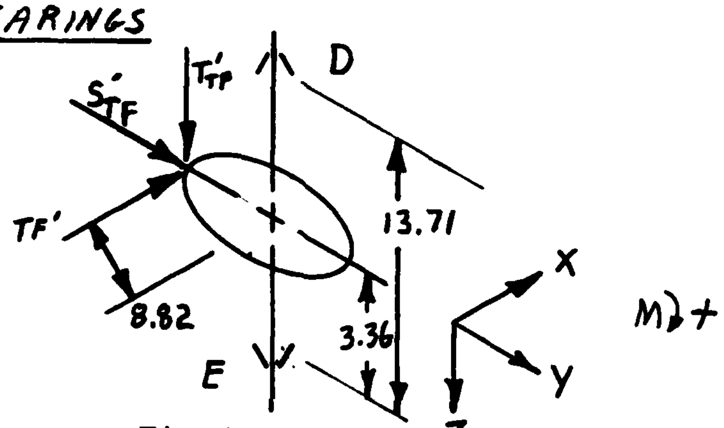

FIG. 4

$$\Sigma F_z = 0 = T'_{TF} + F_{EZ}$$

$$F_{EZ} = -T'_{TF} = -4{,}184 \text{ lbs}$$

$$\underline{F_{EZ} = -4{,}184 \text{ lbs}}$$

$$(\Sigma M_E)_{yz} = 0 = -T'_{TF}(8.82) + S'_{TF}(3.36) + F_{Dy}(13.71)$$

$$0 = -(4184)(8.82) + (11137)(3.36) + F_{Dy}(13.71)$$

$$\underline{F_{Dy} = -38 \text{ lbs}}$$

$$(\Sigma M_D)_{yz} = 0 = -T'_{TF}(8.82) - S'_{TF}(10.35) + F_{Ey}(13.71)$$

$$0 = -(4184)(8.82) - (11137)(10.35) + F_{Ey}(13.71)$$

$$\underline{F_{Ey} = 11099 \text{ lb}} \leftarrow \boxed{\Sigma F_y = 0 \quad 11099 + 38 = 11137 \checkmark}$$

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REPORT

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DESIGN NO.	SUBJECT		WBS
M-169	PCH-1 HYBRID BEARING LIFE CALC		
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$$\left(\Sigma M_E\right)_{xz} = 0 = TF'(3.36) - F_{Dx}(13.71)$$

$$0 = (17080)(3.36) - F_{Dx}(13.71)$$

$$\underline{F_{Dx} = 4186 \text{ lbs.}}$$

$$\left(\Sigma M_D\right)_{xz} = 0 = TF'(10.35) - F_{Ex}\,(13.71)$$

$$0 = (17080)(10.35) - F_{Ex}\,(13.71)$$

$$\underline{F_{Ex} = 12894 \text{ lbs.}}$$

$$\Sigma F_x = 0 = 4186 + 12894 - 17080 \checkmark$$

RESULTANT FORCES

$$F_{DR} = \left[F_{Dx}^2 + F_{Dy}^2\right]^{1/2} = \left[4186^2 + 38^2\right]^{1/2}$$

$$\underline{F_{DR} = 4186 \text{ lbs}}$$

$$F_{ER} = \left[F_{Ex}^2 + F_{Ey}^2\right]^{1/2} = \left[12894^2 + 11099^2\right]^{1/2}$$

$$\underline{F_{ER} = 17013 \text{ lbs}}$$

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M-169	PCH-1 HYBRID BEARING LIFE CALC		
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FOR TIMKEN BEARINGS - USE TIMKEN FORMULAS

$$\frac{.47 R_A}{K_A} \overset{?}{\gtrless} \frac{.47 R_B}{K_B}$$ WHEN $R_A = F_{ER} = 17013$
$R_B = F_{DR} = 4186$
$K_A = K_B = 1.79$
$T_A = 4184$

$$.47(17013) > .47(4186)$$

∴ FOR EQUIVALENT RADIAL LOAD (RE)

$$R_{EA} = 0.53 R_A + 0.47 R_B + K_A T_A = R_{EE}$$

$$\underline{R_{EB} = R_B = 4186 \text{ lbs.}}$$

$$R_{EE} = (0.53)(17013) + (0.47)(4186) + (1.79)(4184)$$

$$\underline{R_{EE} = 18,474 \text{ lbs}}$$

THE BEARING LIFE BEARING E PORT

$$L_{10E} = \left(\frac{C(90) \times SF}{P}\right)^{3.3} 3000 = \left(\frac{(22400)(.7548)}{18474}\right)^{3.3} 3000$$

~~B-10 LIFE FOR BEARING E PORT = 2233~~
B-10 LIFE FOR BEARING E PORT = 2930 (C90 = 24300)

$$L_{10D} = \left(\frac{C(90) \times SF}{P}\right)^{3.3} 3000 = \left(\frac{(22400)(.7548)}{4186}\right)^{3.3} 3000$$

B-10 LIFE FOR BEARING D PORT = 314,800

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LOWER GEARBOX

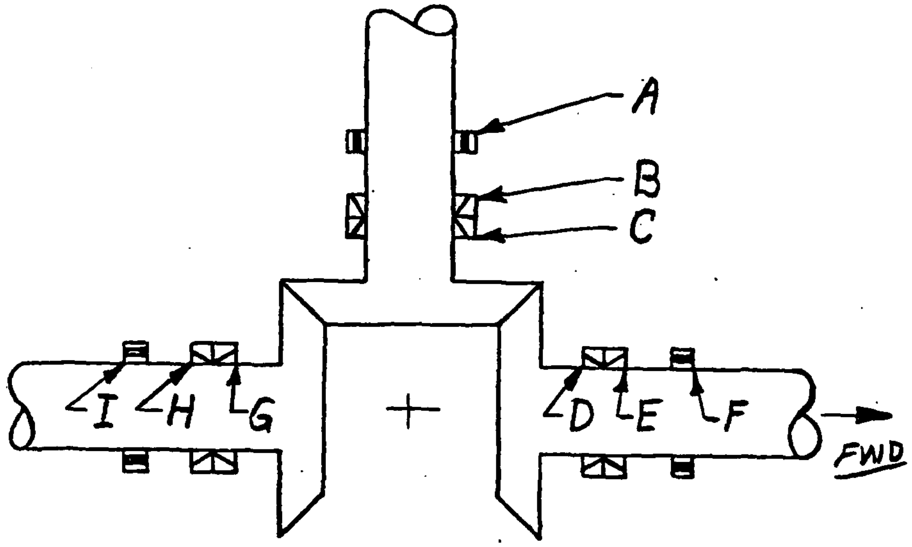

FIG. 5

A - TORRINGTON HJ-8010436; BDC = 51900

B - TIMKEN 71437-71750; BRR = 14,400 lbs., K = 1.40

C - TIMKEN H924045-H924010; BRR = 17,800 lbs, K = 0.87

D, E, G, H - TIMKEN M238849-M238810; BRR = 24,200 lbs, K = 1.76

F, I - TORRINGTON HJ-8811248; BDC = 69,100 lbs.

BEARINGS LISTED ARE IN ACCORDANCE WITH REF 2 AND 3.

DETERMINE MEAN TORQUE

1) ALL BEARINGS ARE ROLLER BEARINGS
$\therefore\ T_m = 0.955\ T_1$ (ref. pg. 4)

$$T_1 = (61700)\left(\frac{51}{20}\right) = 157335\ \text{lb.in.}$$

$$T_m = (157{,}335\ \text{lb.in.})(0.955)$$

$$T_m = 150{,}255\ \text{lb.in.}$$

$$\text{MEAN RPM.} = 3256\left(\frac{20}{51}\right)$$

$$RPM_m = 1277$$

THE TOTAL OF THE TANGENTAL FORCES ON THE PINION TF_m

$$TF_m{}^{①} = T_m \frac{1}{5.13} = 150{,}255\ \frac{1}{5.13}$$

$$TF_m = 29{,}290\ \text{lbs.}$$

IN THE PORT GEARBOX THE PINION IS A L.H. GEAR DRIVING C.W. ①
IN THE STBD GEARBOX THE PINION IS A R.H. GEAR DRIVING C.C.W ①
THE REST OF THE PINIONS' PROPERTIES ARE IDENTICAL ①

SPIRAL ANGLE $(\psi) = 30°$ ①
PRESSURE ANGLE $(\phi) = 25°$ ①
PITCH ANGLE $(\gamma) = 37°7'$ ①

① RELATIONSHIPS PER. REF #3.

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① $T_{TF} = \frac{TF_m}{\cos\psi}(\tan\phi \sin\gamma + \sin\psi \cos\gamma)$

$T_{TF} = \frac{29,290}{\cos 30}(\tan 25 \sin 37.1166 + \sin 30 \cos 37.1166)$

$T_{TF} = \frac{29,290}{0.86603}\left[\overbrace{(0.46631)(0.60344)}^{.28139} + \overbrace{(.5)(.79741)}^{.39871}\right]$

$T_{TF} = 23,000 \text{ lbs}$

① $S_{TF} = \frac{TF_m(\tan\phi\cos\gamma - \sin\psi \sin\gamma)}{\cos\psi}$

$S_{TF} = \frac{29,290}{\cos 30}\left[\tan 25 \cos 37.1166 - \sin 30 \sin 37.1166\right]$

.07012

$S_{TF} = \frac{29290}{.86603}\left[\overbrace{(.46631)(.79741)}^{.37184} - \overbrace{(.5)(.60344)}^{.30172}\right]$

$S_{TF} = 2,371 \text{ lbs}$

① THESE LOADS ARE DIVIDED BETWEEN THE FWD AND AFT MESHES AS FOLLOWS (60% FWD 40% AFT)

	TF	T_{TF}	S_{TF}
FWD MESH	17,574	13,800	1,423
AFT MESH	11,716	9,200	948

① RELATIONSHIPS PER REF #3

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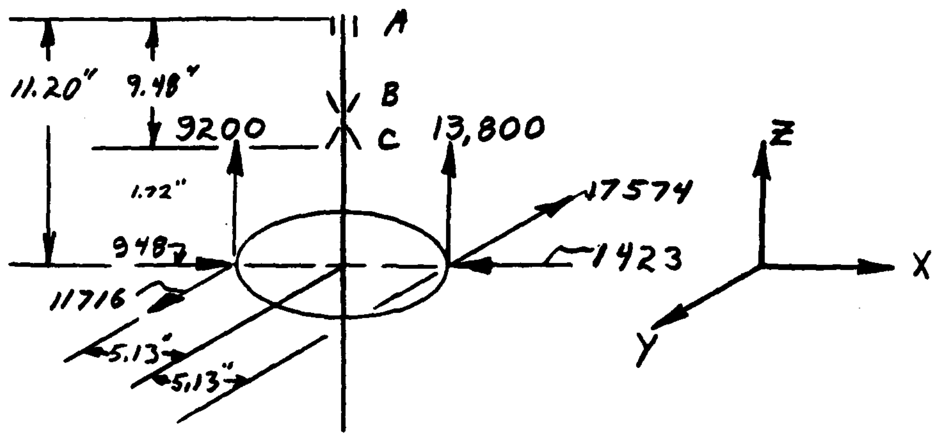

FIG. 6

$$\Sigma F_z = 0 = 9200 + 13800 - F_{cz}$$

$$F_{cz} = 23000$$

$$\left(\Sigma \overset{+}{M_A}\right)_{zy} = 0 = \overset{5320}{(1423-948)(11.20)} + \overset{-23598}{(9200-13800)5.13}\ \ {}^{-18278}$$

$$+F_{cx}\,(9.48)$$

$$F_{cx} = \frac{18278}{9.48} = 1928 \leftarrow$$

$$\underline{F_{cx} = 1928\ \text{lbs.}}$$

$$(\Sigma M_c)_{zx} = 0 = \overset{817}{(1423-948)(1.72)} + \overset{-23598}{(9200-13800)\,5.13} + F_{Ax}\,9.48 \quad \overline{22781}$$

$$\underline{F_{Ax} = 2403} \rightarrow$$

$$\Sigma F_x = 0 = 948 - 1423 + F_{Ax} + F_{cx} = 948 - 1423 + 2403 - 1928 = 0 \checkmark$$

?

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$M \downarrow +$

$$\left(\Sigma M_A\right)_{zy} = 0 = \underbrace{(11716 - 17574)(11.2)}_{-65609.6} + F_{Cy}\,(9.48)$$

$\underline{F_{Cy} = 6920 \text{ lbs. } +y}$

$$\left(\Sigma M_C\right)_{zy} = 0 = \underbrace{(11716 - 17574)(1.72)}_{10075} + F_{Ay}\,(9.48)$$

$\underline{F_{Ay} = 1062 \text{ lbs } -y = -1062}$

$\Sigma F_y = 11716 - 17574 + 6920 - 1062 = 0$ ✓

DETERMINE RESULTANT FORCES

$$F_{AR} = \left[2403^2 + (-1062)^2\right]^{1/2} = 2627$$

$\underline{FAR = 2627 \text{ lbs.}}$

$$FCR = \left[1928^2 + 6920^2\right]^{1/2}$$

$\underline{F_{CR} = 7184 \text{ lbs}}$

$$R_{EC} = 0.53\,F_{CR} + 0.47\,\cancel{F_{BR}}^{\,0} + K_C\,F_{CZ}$$

$$R_{EC} = (0.53)(7184) + 0 + (0.87)(23000)$$

$\underline{R_{EC} = 23818 \text{ lbs.}}$

$$\text{SPEED FACTOR} = \left(\frac{500}{RPM}\right)^{.3} = \left(\frac{500}{1277}\right)^{.3} = .7548$$

$$\text{LIFE} = \left(\frac{C(90) \times SF}{R_{EC}}\right)^{3.3} \cdot 3000 = \left(\frac{17800\ .7548}{23818}\right)^{3.3} 3000$$

B-10 LIFE FOR BEARING C = 445 HOURS

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GRUMMAN AEROSPACE CORPORATION

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BEARING B IS THEORETICALLY UNDER ZERO LOAD. ACTUALLY, IT PROBABLY FEELS A RELATIVELY SMALL LOAD, BUT IT SEEMS SAFE TO SAY THAT IT'S B-10 LIFE WILL EXCEED 10,000 HOURS. (1)

B-10 LIFE FOR BEARING B = 10,000 HOURS

BEARING "A" TORRINGTON

TORRINGTON SPEED FACTOR @ 1277 RPM.

$SF = 2.94$

LIFE FACTOR

$$LF = \frac{BDC}{SF \quad F_{AR}} = \frac{51900}{(2.94)(2627)}$$

$LF = 6.722$

$B10 \text{ LIFE} = 500 \; LF^{3.3}$

B-10 LIFE OF BEARING A > 260,000 HOURS

(1) RELATIONSHIP PER. REF. #3

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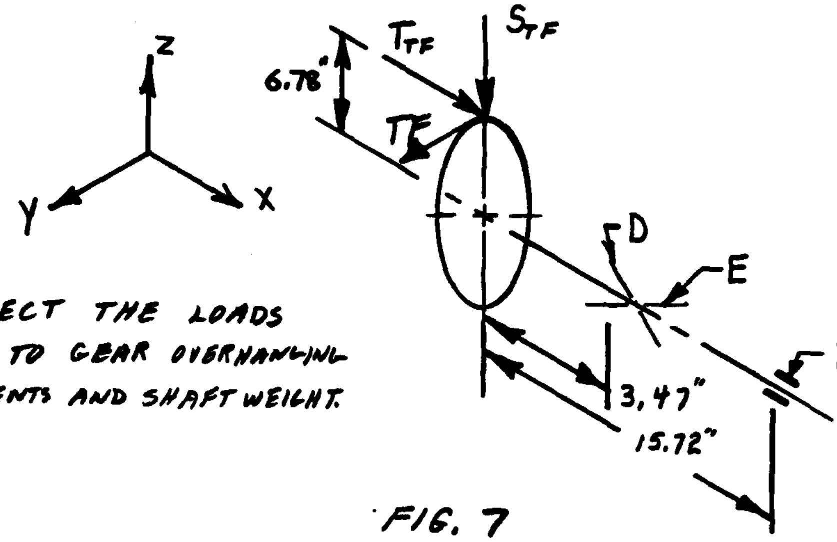
FOR FORWARD GEAR.



1) NEGLECT THE LOADS DUE TO GEAR OVERHANGING MOMENTS AND SHAFT WEIGHT.

FIG. 7

FROM FIG 6 pg. 18

S_{TF} = 13800 lbs.
T_{TF} = 1423 lbs.
TF = 17574 lbs.

$$\Sigma F_x = 0 = T_{TF} + F_{Dx} = 1423 + F_{Dx}$$

$$\underline{F_{Dx} = -1423 \text{ lbs.}}$$

$$\overset{M\circlearrowright+}{(\Sigma M_F)_{zx}} = 0 = T_{TF}\,6.78 - S_{TF}\,15.72 + F_{Dz}\,12.25$$
$$0 = (1423)(6.78) - (13800)(15.72) + F_{Dz}\,12.25$$

$$\underline{F_{Dz} = 16920 \text{ lbs.}}$$

$$(\Sigma M_D)_{zx} = 0 = T_{TF}\,6.78 - S_{TF}\,3.47 + F_{Fz}\,12.25$$
$$0 = (1423)(6.78) - (13800)(3.47) + F_{Fz}\,12.25$$

$$\underline{F_{Fz} = 3120\downarrow = -3120}$$

$$\Sigma F_z = 0 = -13800 + 16920 - 3120$$ ✓

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MARINE DESIGN ANALYSIS

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$$(\Sigma M_F)_{YX} \overset{M\circlearrowright+}{=} 0 = F_{DY}\ 12.25'' - TF\ 15.72''$$

$$0 = F_{DY}\ 12.25 - (17574)(15.72)$$

$$\underline{F_{DY} = -22552}$$

$$(\Sigma M_D)_{YX} = 0 = F_{FY}\ 12.25'' - TF\ 3.47''$$

$$0 = F_{FY}\ 12.25 - (17574)(3.47)$$

$$\underline{F_{FY} = +4978}$$

$$\Sigma F_Y = 0 = F_{FY} + F_{DY} + TF = +4978 - 22552 + 17574 \checkmark$$

$$FDR = \left[(-22{,}552)^2 + 16{,}920^2\right]^{1/2}$$

$$\underline{F_{DR} = 28{,}194 \text{ lbs.}}$$

$$F_{FR} = \left[4{,}978^2 + 3{,}120^2\right]^{1/2}$$

$$\underline{F_{FR} = 5{,}875 \text{ lbs.}}$$

CALCULATE MEAN SPEED. $-\left(1277 \cdot \frac{28}{37}\right) = 966\ RPM_m$

$$RPM_m = 966$$

<u>BEARING F.</u> TORRINGTON SPEED FACTOR @ 966 = 2.74

$$LF = \frac{BDC}{SF\ FFR} = \frac{69100}{(2.74)(5875)} = 4.29$$

$B_{10} = 500\ LF^{3.3}$

<u>B10 LIFE FOR BEARING F = 61,000 HOURS</u>

GAC 4001A

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MARINE DESIGN ANALYSIS

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BEARING D.

$RE_D = 0.53\ F_{DR} + 0.47\ \cancel{F_{ER}}^{0} + 1.76\ F_{DX}$ OR F_{DR} WHICHEVER IS GREATER

$RE_D = (0.53)(28,194) + 0 + (1.76)(1,423)$

$RE_D = 17,447$ lbs. OR 28,196

$\therefore$ RED = 28,196

SPEED FACTOR $= \left(\frac{500}{966}\right)^{.3} = .8207$

LIFE BEARING D $= \left(\frac{(24200)(.8207)}{28,196}\right)^{3.33} 3000$

B-10 LIFE FOR BEARING D = 932 HOURS

BEARING E

$RE_E = 0.53\ \cancel{F_{ER}}^{0} + K_E\left(\frac{0.47\ F_{DR}}{K_D} - F_{DX}\right)$

$RE_E = 1.76\left(\frac{(0.47)(28194)}{1.76} - 1423\right)$

$RE_E = 10747$ lbs.

LIFE BEARING E $= \left(\frac{(24200)(.8207)}{10747}\right)^{3.33} 3000$

B-10 LIFE FOR BEARING E = 23,236 HOURS

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GRUMMAN AEROSPACE CORPORATION
MARINE DESIGN ANALYSIS

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① SINCE THE LOADS ON BEARINGS (G, H + I) ARE 66.67% OF THE FWD BEARING LOADS, THE B-10 LIFE OF THESE BEARINGS WILL BE PROPORTIONAL, BY THE 10/3 POWER, LONGER.

$$\frac{\text{B-10 LIFE OF AFT BRGS}}{\text{B-10 LIFE OF FWD BRGS}} = \left(\frac{2}{3}\right)^{10/3}$$

$$\therefore \text{B-10 LIFE OF AFT BRGS.} = \left(\frac{3}{2}\right)^{10/3} (\text{B-10 LIFE OF FWD BRG})$$

B-10 LIFE OF AFT BRGS. = 3.86 B-10 LIFE OF FWD BRG.

B-10 OF G = (3.86)(B10 D) = (3.86)(932) = 3,600 HOURS

B-10 OF H = (3.86)(B10 E) = (3.86)(23236) = 89,700 HOURS

B10 OF I = (3.86)(B10 F) = (3.86)(61,000) = 7230,000 HOURS

GRUMMAN AEROSPACE CORPORATION

MARINE DESIGN ANALYSIS

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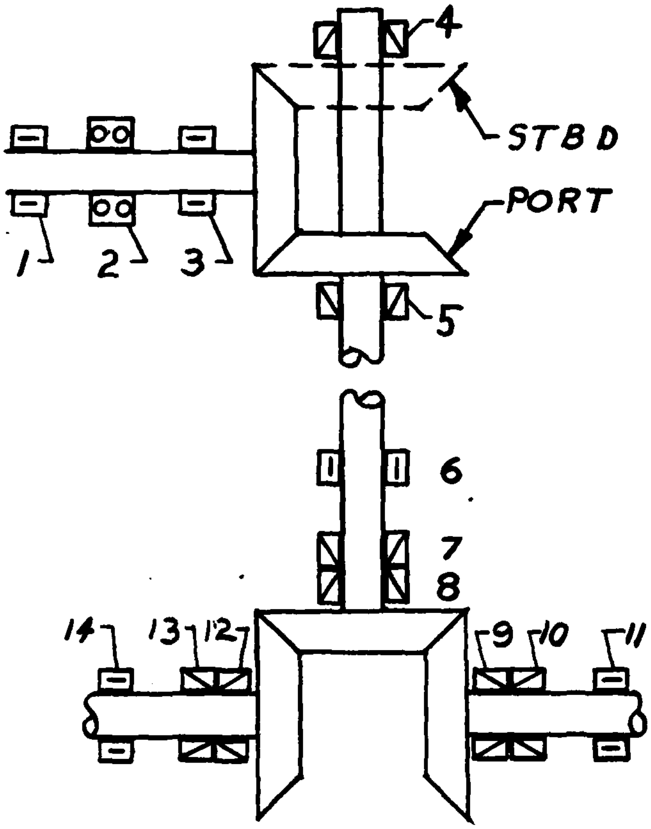
SUMMARY



BRG. B-10 LIVES - HOURS			
BRG	PORT	STBD.	CEVM
1	11 000		
2	716		2148
3	563		1689
4	>300 K	2936	
5	2930	>300K	
6	>200K		
7	10,000		
8	445		1335
9	932		2796
10	23236		
11	61 000		
12	3600		
13	89700		
14	>200K		

RECOMMENDATIONS.

IT IS RECOMMENDED THAT THE STANDARD BEARINGS WITH B-10 LIVES LESS THAN 1000 HOURS BE REPLACED WITH BEARINGS MADE OF CEVM MATERIAL. USING BEARINGS OF CEVM MATERIAL WILL INCREASE THE BEARING LIVES THREE-FOLD, THERE-BY PROVIDING A REASONABLE MEAN TIME BETWEEN FAILURES FOR THE TEST PROGRAM.

REFERENCES.

1. FOILBORNE UPPER GEARBOX ASSEMBLY
   PCH-1 203-1993333

2. FOILBORNE NACELLE TRANS. ASSEMBLY
   PCH-1 203-1993332

3. PCH-1 MOD-1 FOILBORNE TRANSMISSION
   BEARING B-10 LIFE CALCULATIONS.
   BOEING REPORT NO. AMV PCH-MOD-1-573
   DATED JAN. 24, 1969

DATE
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